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Mines Branch Program
on Environmental Improvement

FOURTH MINES BRANCH SEMINAR ON ENVIRONMENTAL IMPROVEMENT

by

THE STAFF

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THE FOURTH MINES BRANCH SEMINAR ON ENVIRONMENTAL IMPROVEMENT

Toward Pollution - Free Mineral and Energy Processes

FOREWORD

by

John Convey

On the occasion of the three previous seminars of this series, I described our Environmental Improvement Program sufficiently that it need not be repeated here. Thus, it need only be explained that this report records contributions to pollution abatement at mineral and heat process sources by the Mines Branch during 1972.

The report does not include some related Mines Branch research in which contributions have been only marginal and where it is felt that the relevant engineering and scientific literature is adequate; one example is the fluidized-bed combustion technique.

In an attempt to stimulate dialogue and broaden participation, the fourth seminar will be dedicated to discussion of these contributions which are being circulated one month in advance of the meeting. If these discussions prove to be significant, they will be summarized for inclusion with the proceedings of the next seminar.

Readers are encouraged to comment in writing on any of the contributions to this proceedings and to attend the seminar scheduled for 28 February, 1973 at Camsell Hall, 588 Booth Street, Ottawa, K1A 0E4. Written discussion should be addressed to E.R. Mitchell and F.T. Rabbitts, Co-chairmen, Mines Branch Environmental Improvement Program, 555 Booth Street, Ottawa, K1A 0G1.

John Convey
January, 1973

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Mines Branch Committee on Environmental Improvement

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MINE ENVIRONMENTAL CONTROL PROGRAM

by

G. Knight

ABSTRACT

The prime research objective of the Environmental Control Program of the Mining Research Centre is to improve the quality of the mine environment, even though deeper mines and more powerful machines render maintenance of standards more difficult. The approach is to improve instrumentation and understanding of the basic physical and chemical processes involved.

The program in the last year has expanded from dust and radiation and now includes noise, spontaneous combustion, methane emission, and combustion products from explosives.

Dust and radiation studies are in the two fields, instrumentation and dust-radon-rock relationships. Noise studies are concerned with instrumentation, noise levels in mines, and the physical basis for specifying noise levels. Spontaneous combustion is concerned with classifying Canadian coal types and examining the basis for instrumental early detection monitors. Methane studies are concerned with classifying Canadian coal types.

PROGRESS IN 1972

1. Mine Air Quality - Physical

The final report on the antecedent project, "Clean-up of mine air by underground filtration", was issued this year and a paper presented at the USAEC Air Cleaning Conference.

The work under the project, "Calibration of laboratory and field

equipment", was completed in 1972 with the installation of a massive lead shield around the gamma-ray detector and check calibrations. This equipment can now be used for measurement of small quantities of gamma-emitting substances.

The main work this year has been on development of sampling instruments and on dust-radon-rock relationships.

(1) Development of Instruments and Sampling Procedures

1) Routine Dust Sampling Instruments

The co-operative project with McIntyre Research Foundation and the Mines Accident Prevention Association of Ontario has concluded the active laboratory-based stage of the study with the conclusions:

(i) personal gravimetric samplers can be used in metal mines either as personal or as fixed position samplers;

(ii) quartz can be assessed on the resulting samples by X-ray diffraction analysis;

(iii) quartz assessment on each sample is essential in high quartz operations;

(iv) the personal dust sampler can be issued and collected at the headframe;

(v) the personal sampler is subject to damage in narrow manways and needs some minor modifications. Prototype modified samplers are being built. In these, the dust sampler is being combined with the caplamp battery for the maximum convenience in use.

(vi) the next stage is the use of the modified samplers in a few mines by mine staff during 1 or 2 dust survey periods (6 to 12 months).

Five internal reports (72/20, 72/31, 72/42, 72/99, and 72/108) as well as an external report (R. Yourt) on this subject have been published. A full

report is being prepared for publication.

The modifications proposed by the Elliot Lake Laboratory (70/114) to the M.R.F. dust sampler (for sampling aluminum powder used as a prophylactic for silicosis) have now been promulgated by the McIntyre Research Foundation (E. Newkirk).

The analysis of quartz by X-ray diffraction on mine samples has proceeded smoothly this year. It is clear that interference by other minerals is very common, but can be allowed for by examining three or four of the stronger quartz diffraction lines until the interference problems have been sorted out for each mine. In some mines, the interferences have been found to vary from sample to sample and measurements on two lines are always needed.

2) Routine Radon Gas and Radon Daughter Instrumentation and Technique

The laboratory calibration technique for assessment of alpha particles has been set up, and first tests are satisfactory. This equipment is to be used for calibration of field instruments and studies on radon gas and daughter behaviour.

The technique in use for radon daughter measurement is under intensive review in order to determine sources of error and improve the individual processes in the technique as well as suggesting replacements for some of the obsolescent equipment in use. A selected number of types of sampling filter are being examined for air flow, pressure drop, dust collection efficiency and radon daughter counting efficiency. A report is being prepared on these results. This study, it is hoped, will lead to the substitution of a lighter, more convenient pump and battery pack. The work is now moving into the study of the assessment of working level from alpha particle counts in order to improve its accuracy and, if possible, eliminate

the one-hour waiting period involved in the Kuznetz method. Two or three further reports on radon daughter instrumentation should be prepared this year.

The routine radon gas sampling and measuring procedure presently in use has been reviewed, and a report is being prepared on the difficulties encountered in its use and on several proposed alternative improved techniques.

3) Dosimeter Approach to Routine Measurements

Some very preliminary work on methods for detecting radon daughters suitable for a dosimeter has been done; however, since intensive work is being conducted in the United States on a suitable detector system, this study has been shelved until the state of the art permits further consideration of a combination of personal dust and radiation samplers without duplicating the work of other investigators.

(2) Dust-Radon-Rock Relationships

The laboratory breakage test has now been developed and a report prepared. Three ores have been tested, the results are being analyzed, and a report is being prepared.

Mineral Composition. The semi-quantitative techniques of X-ray diffraction analysis have been developed for about 20 minerals other than quartz. The accuracy attainable is very variable and depends on factors such as shading in mineral composition as, for instance, with the plagioclases and preferred orientation as with muscovites. Some preliminary tests on neutron activation analysis have shown that it can be useful for some elemental analyses of mine airborne dust and a report is being prepared.

Dust and Radon Sources. This project has been delayed by equipment deliveries.

2. Mine Air Quality - Chemical

(1) Spontaneous Combustion

The objective of this project is to develop an underground monitor to detect early stages of spontaneous combustion in coal mines. The preliminary work has been to review the literature, to study the application of spontaneous combustion detection methods in Canadian coal mines, and to test by the adiabatic method the liability of Canadian coals to produce spontaneous heat. Literature has been reviewed in "Literature Survey and Feasibility Report on the Detection of Spontaneous Combustion in Coal Mines" (IR 72/70).

A review of past occurrences of spontaneous heating in some coal mines abroad as well as in western Canada has been made, and various factors responsible for spontaneous heating have been reviewed. A report on spontaneous heating, related to both mining methods and ventilation systems has been issued (IR 72/102). It is concluded that a serious problem might arise in some Canadian mines as they work deeper and that further research is justified.

A visit was made to Canmore Mines Ltd., Kaiser Resources Limited, and McIntyre Porcupine Mines Limited from September 10th to 22nd. Coal samples have been taken from each colliery for testing by the adiabatic method and the differential temperature method. A field survey of ventilation systems and mining methods was made. From the adiabatic tests and field surveys, assessments will be made to determine the susceptibility of western Canadian coals to spontaneous combustion.

Fisher Victoreen Series 4400 gas chromatograph with dual-flame ionization detector, dual-thermal conductivity detector and cryogenic accessory, and two pen recorders have been ordered. These instruments are used for

spontaneous combustion and methane emission study.

(2) Methane Emission

Apparatus for the volumetric method of measuring the methane sorption capacity of coal was constructed. Five high-pressure volumetric sample capsules from the Metallurgical Fuel Engineering Group have been tested up to pressures of 1000 psig for 24 hours. The volume of the capsules has been calibrated. Different volatile matters of coal from Morrison-Knudsen Inc. have been tested. A report on the apparatus for the determination of methane sorption on coal at high pressure by a volumetric method has been written (IR 72/133). The preliminary results indicated that sorption capacities show considerable variation between coals and no general connection between volatile matter and methane sorption capacity has been established.

The apparatus for determination of methane sorption by the gravimetric method has been built. A 30-ml. aluminum capsule has been constructed. It was tested with nitrogen gas at pressures up to 1200 psig without yielding. The total weight of the capsule is 149 grams, which is 11 grams less than the maximum weight limit (160 grams). The capsule is thus satisfactory for determination of methane sorption by the gravimetric method.

The literature survey and feasibility report on methane emission in underground coal mines is under way. This review will be completed in December, 1972.

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UNDERGROUND DIESEL PARTICULATE EMISSIONS

by

E.D. Dainty and J.P. Mogan

ABSTRACT

A testing facility has been constructed for the certification of diesel-powered mining equipment for flameproofness and ventilation requirements. The facility includes a 400-HP dynamometer with sophisticated control gear, an explosion bunker for flameproof testing under load, temperature and pressure monitors, volumetric device for fuel flow, venturi meters for combustion, and a standard cart for testing motor vehicle emissions for CO, CO_2, NO, NO_2, and O_2. This equipment is ideally suited to applied research into the various characteristics of the power trains used in diesel mining equipment.

PROGRESS IN 1972

During the first part of the year, much of the engine control gear and readout systems were checked. A "black box" to measure some of the engine variables in situ has been constructed. This will be calibrated by means of the dynamometer and can be used for field testing in both research and certification programs.

Because of the interest expressed (by The Mining Research Centre, The International Nickel Company, and the Ontario Mining Association) in the contribution of diesel particulate emissions to the 'combustible' dust which has been detected in the general body of mine air, a study was begun to evolve the necessary techniques to monitor this component of diesel emissions (1). Samples of raw diesel exhaust were passed through glass

fibre filters to determine the amount of particulates. Particles were also collected on membrane filters so that the diameters could be determined from electron micrographs.

The measured concentrations of particulates agreed well with those quoted in the literature (2). The diameters of the elementary particles - 0.1 to 0.5 microns - and of the agglomerates - 0.5 to 25 microns - also agreed with previous findings (3). Some typical test results for the raw exhaust of this direct-injection, in-line, six-cylinder engine are shown in Table 1.

Table 1

Run No.	RPM	Fuel/Air Ratio	Torque ft.lb.	CO %	NO %	Exhaust Rate cfm
17	2200	0.056	228	0.43*	0.105	176
19	1000	0.062	236	1.36*	0.102	80

Run No.	Particulate Loading mg/m^3	Particulate Rate gm/min.	BMRC Respirability Factor	Ventilation for 50 ppm CO - cfm	Ventilation for 12.5 ppm NO_x - cfm	Ventilation for 3.5 mg/m^3 carbon cfm
17	722	3.6	39.0%	14,100	13,700	13,980
19	1410	3.2	19.1%	20,100	6,000	6,060

* Exceeds maximum allowable CO in the undiluted exhaust.

Although these ventilation rates are not realistic because the engine would be derated for underground service, they do indicate the relative importance of the particulate emissions. The large increase in ventilation requirement for Run #17, even though the gross particulate rate was similar to Run #19, illustrates the importance of an accurate analysis of particle size if particulates are to be included in ventilation criteria.

Currently, a new Deutz V-6 indirect-injection diesel has been installed in the dynamometer facility. Exhaust gas may be sampled independently from each bank of cylinders before and after passing through a new or used oxy-catalytic scrubber. The installation approximates the configuration used in the Wagner L.H.D. machines at International Nickel. A 4-stream module for handling a sample and a sample divider to control the opacity of size distribution samples are currently under construction.

FUTURE RESEARCH

On completion of a certification investigation of a diesel shuttle car for Noyes Bros. Pty., a study will be done to establish base-line emission values with the new Deutz diesel. Then a co-operative research program will be begun with the International Nickel Company and Deutz Diesel of Canada to assess the changes in these values as a similar engine progresses from "just rebuilt" to fully "worn-out" in mining service.

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THE DESULPHURIZATION OF OIL BEFORE COMBUSTION

by

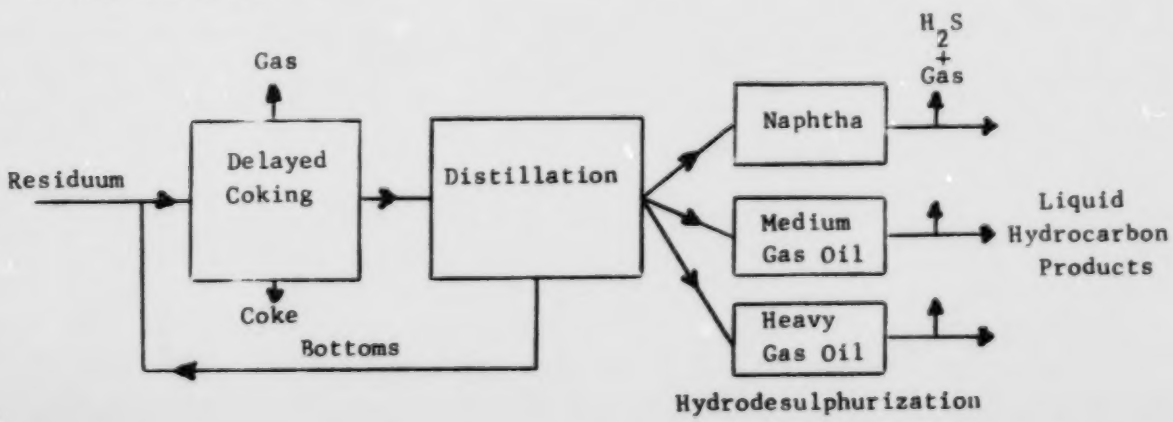
B.I. Parsons

ABSTRACT

The engineering research program of the Hydrocarbon Group is primarily concerned with the development of hydrogenation and desulphurizing systems for the refining of low-grade oils and tars. The objective of the program is to produce clean liquid fuels from low-quality petroleum at reasonable cost. The basic technology for the production of clean fuels by hydrogenation has existed since the 1930's. The demands now are for means of a) simplifying the systems which are used and b) maximizing the yields of clean fuels with a view to relieving the shortage anticipated in the next decade.

PROGRESS IN 1972

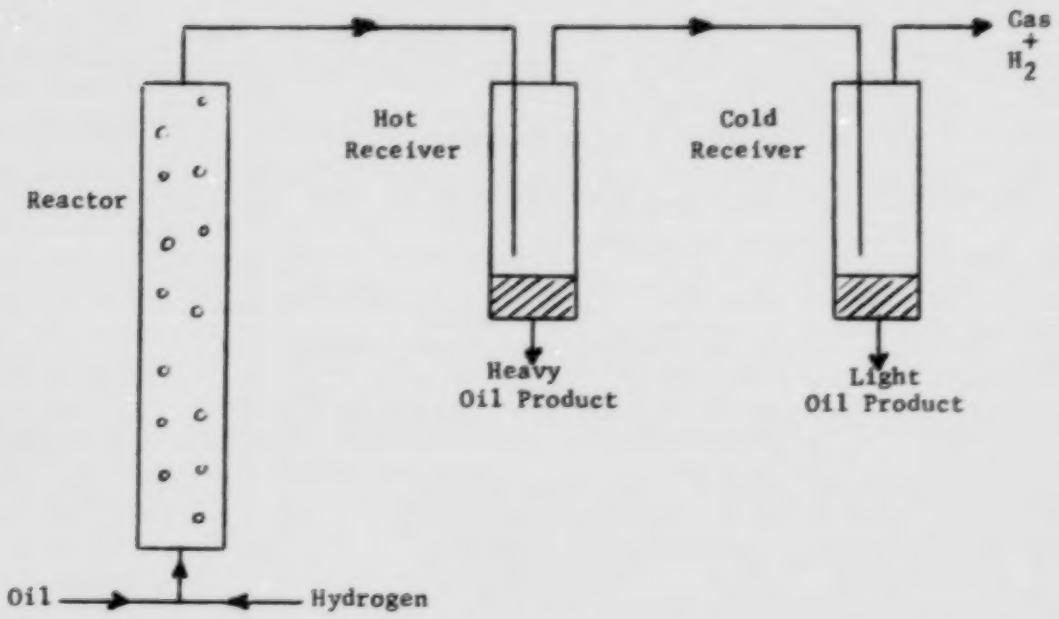
The classical procedure for refining low-grade oils and tars is a three-step process in which part of the high-molecular-weight asphaltics and resins are cracked by thermal coking, followed by distillation and the hydro-desulphurization of the vapours to form low-sulphur, marketable, liquid hydrocarbons.



This classical approach has the practical advantage of concentrating all the chemically combined metals, the more refractory hydrocarbon material, and a sizable proportion of the sulphur in the coke. However, it suffers also from a very real disadvantage in that the yield of liquid fuel material generated is low. Under the best of conditions, the yield of usable liquid fuels created from the residuum in the coking step does not exceed 45 - 50 %. Traditionally the material balance in the 3-step procedure is maintained by burning the coke for power generation, but it is unlikely that any government can afford to permit the burning of such foul fuel on a scale ever increasing with oil production. Certainly, it is highly unlikely that any new plants will be approved and it is the new plants that we are mostly concerned about.

A second drawback to the coking process is that it is a batch process and a mechanically complicated procedure (relatively speaking), both maintenance and labour intensive. This is perhaps of less importance in the more accessible and densely populated parts of the world, but it is a very important factor in remote areas such as the Canadian North.

There are at least two viable alternatives to the coking step in the 3-stage process. The first is low-pressure (1000 - 1500 psi) thermal hydrocracking and the second is catalytic hydrocracking at moderate pressures (1500 - 2500 psi). Both processes have been the subject of active study during the past year. The type of equipment used in both the thermal and catalytic processes is essentially the same. In the thermal case, the reactor is used empty (no packing) and, in the catalytic process, a powdered catalyst is fluidized in the flowing oil. In principle, the apparatus appears as follows:



The unit is operated, in effect, as a continuous flow, liquid phase system with the oil and hydrogen percolating up through a long narrow pipe reactor. Any low-boiling material present in the feed (or produced in the course of reaction) vapourizes, collects as bubbles, and quickly passes out of the reaction zone. High boiling fractions and the residuum hydrocarbon, on the other hand, remain predominantly in the liquid phase and progress slowly up the reactor by displacement only. In this arrangement, the contact time of the fractions upon which the most work must be done is greatly increased, allowing a substantial reduction in operating temperature, which in turn reduces the amount of sludge and muck formation throughout the system. The net result is higher conversion of the residuum matter to distillate fuels and far less pitch formation.

During the past year, the time of the engineering staff was divided almost evenly between investigations of the thermal and catalytic hydrocracking processes. The feed stock used in all of the current experimental work was bitumen from the Athabasca Tar Sands area.

Thermal Hydrocracking

The problems associated with continuous thermal hydrocracking are largely connected with the accumulation of sludge and coke deposits and the effect of this on the duration of operation before cleaning and maintenance is required. To attain maximum conversion of the residuum fractions to distillable liquid fuels, it is necessary to approach operating conditions favouring coke formation without actually attaining them.

The ease and reliability of the operation of the thermal process were found to improve considerably with operating pressure. Conversion levels of the order of 75 % were possible (and practical) at 1500 and 2000 psi. At 1000 psi it was necessary to cut back on the severity of the operating temperature slightly to sustain continuous operation. The maximum conversion attainable at 1000 psi was approximately 70 %. Under all the conditions investigated, the conversion was markedly improved over delayed coking, where only 45 - 50 % conversion to distillate fuels is practical. Considerable interest has been expressed in the technical feasibility of thermal hydrocracking and, at the present time, contractual work is in progress in this area for one of the oil companies.

Catalytic Hydrocracking

Experimental work in catalytic hydrocracking involves both the operation of the hydrogenation pilot plant and the catalyst preparation facilities. Catalysts suitable for use in liquid phase fluidized bed systems are not commercially available and must be produced in the laboratories of the Fuels Research Centre. In earlier work, it was established that the life of a conventional cobalt or nickel molybdate catalyst formulation is short (50 - 150 hours) with feed stocks such as the Athabasca bitumen, due to the deposition of the chemically combined metals in the oil on to the active sites.

During the past year, the main thrust of the research program has been directed at reducing the cost of preparing an effective catalyst (of the cobalt molybdate type) to compensate in part for the shorter operating life. Normal catalyst preparation procedures result in the active ingredients being distributed throughout the pore structure of the support material and involve as much as 13 - 15 % by weight of active catalyst. It was felt that, in a liquid phase system, the internal area and pores of the catalyst were providing little benefit and that the active components should be concentrated on the external surfaces. During the past year, techniques have been developed to layer the active ingredients on to the external surfaces of a relatively non-porous alumina support.

Catalysts were prepared with 13.1, 3.3, and 1.6 % combined oxides of cobalt and molybdenum and tested in the pilot plant at various temperatures and pressures. A small reduction in the effectiveness of the catalyst was observed with decreasing metals concentration, but, in the main, the results of the experiments confirmed the practicality of the layering technique.

The distillate fractions formed catalytically contained much less sulphur and were substantially more stable than those produced by the purely thermal method. Potentially, the catalytic hydrocracking procedure has the advantage of being able to produce an oil of sufficient stability for direct pipelining to the more central areas without secondary treatment. In the central areas, cheap hydrogen supplies are available from the reforming of gasoline. The combination of a simplified one-stage upgrading procedure for on-site processing, followed by secondary hydrotreating in the more central areas is an interesting possibility and should, in principle, be the cheapest was to produce clean fuels from the Athabasca bitumen and other low-grade northern oils.

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PROGRESS REPORT ON SPECIAL STUDIES RELATED TO CARBONIZATION

by

B.J.P. Whalley

ABSTRACT

R & D objectives of this Group with respect to environmental improvement include contributions to:

1) improved process methods in coal technology especially in formed-coke with a view to substituting low-value coals and waste products for higher-cost coals;
2) abatement of pollution;
3) analytical methods (especially control-type analyses) of determining sulphur, cyanide, and heavy metals in various stages of carbonization processes and in their effluents.

PROGRESS IN 1972

1. Utilization of Waste and Low-Value Products

(1) Utilization of Discarded Automobile Tires in Coking Processes

As mentioned in the third symposium, automobile tires pose a special disposal problem and an investigation in using the rubber in coking processes was initiated. A mix of a reference coal (whose coking properties are well established) and about 3 per cent by weight of shredded rubber tire was carbonized in a 30-lb slot oven. Tumbler tests indicated that although the stability (resistance to breakage) was less than for the reference coal, the stability was sufficiently good to warrant further investigation (1).

(2) Utilization of Coke Fines in Metallurgical Processes

Coke, used in some metallurgical processes that include the electro-reduction of phosphate rock in the production of phosphorus must

meet close size specifications. This greatly increases the cost of the coke unless the undersize can be utilized. Work was done to show how low-value coke fines can be incorporated to make formed coke for use in electro-reduction as well as in other metallurgical processes (2).

2. Development of Methods for Sulphur Analysis

(1) Simultaneous Ash and Total-Sulphur Analysis

The oxygen-flask method was further adapted to permit simultaneous determination of ash and total sulphur (3). This procedure is more useful for control than for precise analysis; some slight loss of precision being exchanged for convenience. The procedure is especially useful where only very small (less than 0.15-g) samples of coal or coke are available as in maceral analyses. An ash determination can be made in about 5 minutes.

(2) Determination of Total Sulphur in Coal by pH Measurement

Investigation was initiated into the reliability of sulphur analysis in coal by measuring the corresponding pH of the combustion gas absorption solution (4). If successful, this approach will be used for control rather than for precise analyses.

(3) Analysis of Cyanide in Coke Oven Effluent

At the request of a Canadian company, referee analyses were done on samples of coke oven effluent for cyanide content. The AWWA distillation-titration procedure was used. It was shown that significant errors could be accounted for by the presence of sulphides, fatty acids, and phenolic-type compounds which are known to interfere, so procedures were adopted to eliminate these errors.

Because of recurrent analytical difficulties by this company, work was started to adapt the "picric acid" procedure, developed by Barkley and Ingles (5) (Extraction Metallurgy Division), to coke oven effluents.

3. Development of Formed-Coke Equipment

It is expected that formed coke* could make a major reduction of environmental pollution in coke making and could make a major contribution in the utilization of Canadian coals as substitute for expensive American low-volatile coals needed in conventional coke ovens.

(1) Bench-Scale Continuous Fluidized-Bed Facility

In order to study form coking processes and the use of Canadian coal in form coking, small-scale automatic continuous fluid-bed units (which were otherwise unobtainable) were being developed at MREC to: (1) enable various aspects of form coking processes to be studied under steady-state conditions; (2) provide products made under closely controlled uniform conditions and in sufficient quantity for subsequent laboratory and pilot plant tests and for statistical evaluations (6).

Units under development included a fluidizer feeder to provide intermittent-continuous flow of fine 60 to 100-mesh coal or char in small (less than 10 g per min.) increments, uniform in weight to within 5 per cent and of uniform size distribution.

The use of heated fluidized-beds in a continuous mode with their inherent uniformity of temperature will permit the close control of variables required in a type of hot briquetting which requires a mixture of two components - (high-volatile coal and char at two different temperatures) under closely controlled particle-size distribution. The fluidized technique will also permit modifying the coking properties of

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*For brevity this will include "hot briquetting" i.e. hot-formed briquettes of coal or char which can be fed uncarbonized to the blast-furnace, where subsequent carbonization occurs.

fine coal by controlled oxidation and of producing continuously a uniform product to specifications.

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POLLUTION ABATEMENT IN THE MANUFACTURE OF METALLURGICAL COKE

by

J.C. Botham

ABSTRACT

Since the previous Mines Branch Seminar on Environmental Improvement, the Metals Reduction and Energy Centre (MREC) has participated to a limited degree in studies directly oriented towards the alleviation of the pollution aspects of coal carbonization and its associated coal processing. Progress in this area is mainly restricted by the dissimilarity between commercial and experimental equipment. However, studies which are indirectly related to pollution control are in progress and include innovations to conventional coke-making in slot-type coke ovens and to the development of new methods of coke manufacture. In this regard, the Canadian Carbonization Research Association recommended that MREC assign priority status to investigations dealing with preheating of coke oven charges, form-coking, and dry-quenching of coke.

PROGRESS IN 1972

Studies by MREC related to pollution control in coal carbonization have, in general, followed the interest of the Canadian coal and coke industry as expressed by the members of the Canadian Carbonization Research Association. The following projects were in progress during 1972.

Coal Charging to Conventional Slot-Type Coke Ovens - The charging of coal into the coke oven is the main contributor (about 60 per cent) to air

pollution in the manufacture of cokes. The following innovations are under consideration by the industry to alleviate this problem:

(1) Preheated coal by pipeline charging

(2) Preheated coal by Redler conveyor system

(3) Preheated coal by larry car

(4) Modifications to the conventional system

Preheated coal "per se" does not reduce air pollution but the systems (1) and (2) being developed for charging hot coal deviate from the normal method in that they are totally enclosed. Methods (3) and (4) are modifications to the present system for control of air pollution. The United States, in general, favours pipeline charging and, in Canada, one coke plant has already decided to install this method.

A proposal was offered to industry by MREC whereby the Mines Branch experimental ovens could be charged by the pipeline technique and would therefore be available for related studies. The proposal was reviewed by the CCRA and turned down as not feasible, the reason being that it is very difficult to reproduce commercial conditions on an experimental scale. Also, exploratory work by Coaltek Associates in this regard is available to one of the member companies. It was generally agreed that MREC would be more fruitfully employed by confining its efforts to an assessment of the effects of preheating on the coke quality, particularly in regard to the specific interests of the association members.

A novel technique of preheating coal that incorporated dry cooling of the coke was presented to CCRA for consideration. Experimental MREC studies based on this principle may be required.

A system whereby the hot coal is conveyed to the coke oven by a Redler conveyer is in use in Germany. This system may be applicable for

experimental studies and its feasibility is presently under joint consideration by MREC and CCRA.

The use of agglomerated coal, either preheated or cold admixed with loose coal, reduces the pollution due to airborne particulates. Initial tests have been made and a project utilizing a packed-bed filter and a preheater has been set-up for in-depth studies. The feasbilility of the elutriation and filtration aspect of the process has been demonstrated and a scale model incorporating a source of hot gas will be constructed to permit evaluation of the entire process (R.D. Warda and R.K. Buhr, P.M.D.).

Dry-Cooling of Coke - The quenching of coke with water from quench towers is the normal procedure and this method contributes to about 10 per cent of the total pollution. In the USSR, it is now mandatory that all new coke ovens use dry cooling techniques. Although this method has not been considered by the North American industry in the past for economic reasons, pollution abatement measures in the U.S.A. are forcing a re-assessment of this technique. MREC has available two units for dry cooling of coke from experimental coke ovens. Initial trials have been made to study the effects of this method of coke quenching on the final quality of the coke. A project presently in progress to correlate the quality of cokes from the Mines Branch test ovens with that of commercial coke will also include an assessment of the merits of dry cooling. It is envisaged that this equipment will ultimately assist industry in this aspect of air pollution control.

Suppression of Coal Dust - Investigations of the use of various suppressant reagents to reduce the loss of fine coal during transportation in open rail cars have continued at the request of a western Canadian coal producer. Similar studies on coal stockpiled at a Canadian steel plant

have been carried out.

Transportation of Coking Coal by Pipeline - The movement of coal slurry via pipeline from mine site to tide water will eliminate the losses of air-borne coal dust normally experienced from moving coal in open cars. Extensive carbonization studies on the effects of pipelining coking coal on its caking and coking properties have been in progress at the Mines Branch for the past two years to assist ShelPac Research and Development Limited in the development of its Cascade Pipeline Project. A similar study for the Canadian National Railways will commence shortly.

Formcoking Studies - Studies related to new processes for the manufacture of coke have continued as outlined in the submission to the previous seminar.

Samples of Canadian coals and U.S.A. coals of interest to the Canadian steel producers have been sent to Europe for an evaluation of their potentials for use in the German BBF process and the French HBNPC process. The chairman of the CCRA Technical Committee and a CCRA research associate visited Europe in October 1972 to witness some of the testing. A report of this investigation is forthcoming.

One of the pilot plant rooms in Building No. 2 (MREC) Corkstown has been redesigned and re-equipped for more intensified investigations in this area.

New test equipment has been acquired, and equipment is under development to provide a greater insight into the quality of high-carbon products for metallurgical use. This equipment includes reactivity testing, high-temperature testing of coke and a Rist apparatus to simulate the conditions in the upper parts of the blast furnace.

Equipment to produce formed cokes and to reproduce the various conditions required for thermal treatment are in the various stages of development.

Travel by members of the staff to Europe and Japan have included visits to laboratories and facilities associated with the development of new techniques in coke manufacture.

It is anticipated that the aforementioned approach to formcoking will provide MREC with the background and the facilities to realistically assist industry in the use of their coal sources in the coke-making processes of the future.

The Use of Antifissurants in Coke Making - The recirculation of high-carbon material such as coke fines, fine coal and flue dust may be categorized as an environmental improvement through disposal of waste material. Such techniques are also used in coke making for other reasons.

CCRA has given a high priority to an MREC antifissurant project. Confidential studies have been carried out for all the integrated steel plants to demonstrate the feasibility of utilizing their coke fines and reducing the quantity of imported premium low-volatile coal used in their coke oven blends. Studies to assist a electric reduction company in the disposal of coke fines was also carried out.

The Special Studies Group (MREC) has engaged in projects to study the mechanism involved in the use of antifissurants with the purpose of predicting coke quality from selected parameters. This work is reported separately in this seminar.

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PROGRESS IN COAL BENEFICIATION STUDIES AND RELATED FLOCCULATION STUDIES

by

J.H. Walsh

ABSTRACT

Improvements to coal beneficiation processes touch on environmental improvement in two ways - first, the products of the processes may be upgraded in either chemical composition or physical form and, second, pollution from the processes used themselves may be abated. The sulphur content of the coal product, its physical form as it affects dust production in shipment storage and handling, and the thermal drying equipment used in coal drying all are related to air pollution; the water used in coal beneficiation can lead to water pollution, and the disposal of the ash rejects leads to aesthetic and drainage considerations.

The pilot plant erected by EMR at the Lingan pit-head of the Cape Breton Development Corporation at the nominal scale of ten tons per hour, two-shift basis, offers an opportunity to test the EMR process at a reasonable scale in continuous operation but under close control.

THE CONTROL OF SULPHUR IN COAL

High-sulphur coal (>1% S) is produced in Canada essentially only in Cape Breton and at a few remaining mines in New Brunswick (Western Canadian coals are usually low in sulphur - typically 0.6% with some lower). High-sulphur coal is used in Canada mostly in Ontario (imported from the U.S.). High-sulphur petroleum coke is used as a fuel at the Athabasca

River "tar-sand" plant, at certain refineries capable of making petroleum coke and in smaller quantities, for certain specialized industrial applications in which not necessarily all the sulphur is vented to the atmosphere. In conventional coke-making, the sulphur divides nearly equally between the coke and the coke oven gas which is processed to lower its sulphur content.

In the long run, coal is expected to be used in only two basic applications - ferrous metallurgy and electric power generation. In the first case, whether conventional or non-conventional coking processes are used, the sulphur in the coke or gas need not escape to the atmosphere. Moreover, processes are available for the removal of sulphur from blast furnace iron whose costs are not directly related to the sulphur content of the iron. Hence, for the metallurgical outlet, an alternative exists to coal beneficiation for sulphur control. For the second outlet, electric power generation, many authorities believe that a second generation of thermal generating plants will be built - those operating according to the so-called combined-cycle technology. In this case, the coal (or other fuel) is gasified by air/steam mixtures under pressure, usually about 300 psi. The sulphur is released to the gas as H_2S, and proven processes are available for its extraction. Thus it may be that no coal beneficiation process will be required for control of sulphur in coal as used in its two main outlets in the future. This applies directly to the Cape Breton coal, the ash content of which is low enough for direct coke making. It must also be noted that the adoption of only one of the two solutions eases the problem greatly - high-sulphur coal would be used by one and the low-sulphur naturally available coal by the other. The problem for the Cape Breton pilot plant is to determine the true distribution of sulphur in the under-the-sea reserve, assess the performance of the coal cleaning

process, and to judge whether a beneficiation plant is justified and, if so, what type of process.

At Lingan, a direct comparison is possible between the performance of heavy-media cyclones and compound water-cyclones. The rest of the process flowsheet involves oil-assisted centrifugal drying and control of water effluent. An important object of the investigation is to determine the water content of the cleaned coal product in relation to the size required to achieve adequate sulphur reduction. In this latter connection, it is interesting to note how developments in one technology affect another. For example, if preheating practices become common in conventional coking practice (itself being adopted largely because of air pollution reasons), then the normal restriction on water content on coal for coking is raised. This arises because only the cost of removing the water is involved rather than a technical upper limit set to control bulk density. Thus finer coal which leads to wetter coal could be used; finer coal leads to better rejection of the pyrite and other mineral matter by allowing better liberation.

Aside from the work at the pilot plant location, other studies are being made by different groups in the Mines Branch to give an improved picture of the chemical and petrographic nature of the pyritic-sulphur distribution in coal. Other separating techniques are being assessed in the Mineral Processing Division. Related studies are being conducted by the New Brunswick Productivity and Research Council (bacterial leaching), University of Western Ontario (electrostatic separation and electron probe analysis), and the University of British Columbia (electron spectroscopy as applied to forms of sulphur in coal). Effort is also being directed towards the development of an on-line total-sulphur analyzer.

FLOCCULATION STUDIES

One element of the pyrite control pilot plant that deserves mention in more detail is the flocculation system to be employed on the waste water circuit. By the use of a suitable flocculant (long-chain or group of long-chains) added to waste water slurries by means of a special cyclonic device which achieves stage-wise building-up of the flocs, it has been found possible to make strong flocs within a relatively narrow size range. These flocs are strong enough to withstand the shearing forces encountered in normal classifier cyclones; thus a relatively compact unit can be used to remove the bulk of the waste matter. The pilot plant also provides an inclined settler of the type recommended by Dr. Puddington of the National Research Council, for the purpose of comparison. In the Edmonton laboratory, other materials besides coal waste are being assessed; these include ferric hydroxide precipitates arising in some hydrometallurgical circuits.

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SULPHUR REMOVAL FROM REDUCING GASES

by

W.A.O. Herrmann

ABSTRACT

The reason for conducting engineering studies on industrial-scale, energy converting, processes is to compare processes with respect to the efficiency of conversion, capital and operating costs, as well as their environmental impact. The purpose of this work is to attempt to pin-point those areas where research may make the greatest contribution to improved performance.

PROGRESS IN 1972

Last year, the concept of a clean fuel gas in a combined gas turbine-steam turbine power plant was examined. This showed the importance of studying and comparing various reducing-gas cleaning processes. This year, because there has been a great deal of interest in the production of synthetic natural gas (SNG) from coal in Canada, a comparison was made of nine processes for removing sulphur from reducing gas on the scale of 250 million cu ft SNG per day.

It was found by calculation that raising the operating pressure of the Alkazid and the Rectisol processes lowered the gas cleaning costs substantially. It was also found that the Rectisol process, costing less to build, can compete with chemically reacting solvents only if the high costs for electrical power for the refrigeration system can be eliminated by installing an absorption system which uses the sensible heat of the gas coming from the water-gas shift conversion. In this case, the operating

costs will be about 83% of those of a corresponding alkazid plant.

The accompanying table compares the better known gas purification systems. Besides the processes employing the physical solvents, water and methanol, it contains data on processes based on chemisorptive solvents and emphasizes some of the differences between these processes. It is these significant differences which dictate the choice of the system for a particular application. Also included for comparison are two processes, the Giammarco and Stretford processes, which extract only the sulphur and produce elemental sulphur in one step. Just as in the Claus process, they oxidize the H_2S according to the following equation.

$$2\ H_2S + O_2 \rightarrow 2\ S + H_2O + \text{heat}$$

These processes recirculate large volumes of an alkaline solution. The oxidation step does not proceed strictly according to the above equation. In order to eliminate the sulphur down to 1 ppmv, there must be a slight excess of oxygen, which leads to the formation of thionates and this causes an appreciable and constant loss. These processes eliminate only the sulphur, they do not dissolve any CO_2, and their main application is the clean-up of the Claus tail gases.

Comparable in their chemistry to these so-called solution Claus processes are the modernized dry-box processes such as the active carbon process. The active carbon process has the advantage of not forming thionates in that it recovers very simply the sulphur in elemental form to lower the sulphur in the effluent gas to 1 ppmv. The Claus equation is reversible, so it is imperative that the temperature of the carbon bed does not exceed 60°C; this requires an elaborate cooling system which does not, as does the Claus furnace, permit heat recovery.

Comparison of Various

Per 1,000 Nm^3/Gas	Pressurized Water	Rectisol (Methanol)	Purisol (N-methyl-pyrrolidone)	Shell Adipic Acid Process
Circulated Solvent m^3	50 to 100	0.5 to 1.0	2.5 to 3.2	3.5
Electric Power kWh	25 to 50	20 (including refrigeration)	4.5 to 6.0	3.5
Cooling Water m^3	-	14	1.5 to 2.0	4.5
Steam kg	-	corresponding to cooling water	30 kg	170 kg
H_2S/CO_2 Inlet Vol %	-	18/40 vol %	-	10 vol %
H_2S/CO_2 Outlet ppmv	-	1 ppm	4 ppmv H_2S 2 vol % CO_2	1 ppmv H_2S 10 ppm org. S
Operating Temp °C	ambient	ambient	40 to 70	-
Regeneration Pressure kg/cm^2	ambient	ambient	10 atm, 140 °C	-
Sulphur Recovery	90%	92%	92%	92%
N-methylpyrrolidone Adipic Acid, Alcazid kg	-	-	0.1	negligible
Methanol, Soda kg	-	0.45	-	-
Hydroquinone, Anthraquinone-sulfonic-acid, A_sO_3	-	-	-	-
$ Investment/1000 Nm^3 Hr Basis: 10^6 Nm^3/hr Power Factor 0,653	-	11,252.86	-	-
Additional $ Investment per ton/hr sulphur recovery Basis: 6 ton/hr S Power Factor 0,54	256,000 (Claus + tailgas)	256,000 (Claus + tailgas)	256,000 (Claus + tailgas)	256,000 (Claus + tailgas)
$ Operating Costs/Ton S	-	98,57*	-	-

*With use of waste heat for refrigeration.

BASF-Alcazid $C_2H_6NCH_2CO_2H$	Ethanolamine $CH_5O\text{-}NH_2$	Hot Potash Solution	Giammarco Vetrocoke Na_3ASO_3	Stretford, 2, 7 Anthraquinone disulfonic Acid
0.7 to 2.0	4	0.05 to 0.1	10 to 15	12 to 20
2	3 to 5	0.04 to 0.07	12	5 to 20
$25m^3$/ton $	corresponding to steam consumption	very little	little	some
1.5-3.0 kg/kg CO_2 4-20 kg/kg S 200 kg/$1000m^3$	200 to 400 kg	1.6 to 2.2 kg	30 kg	20 to 50 kg
10/30 vol %	-	-	Max 2.5 vol %	Max 2 vol %
100 ppmv (with carbon down to 1 ppmv H_2S)	6 ppmv	100 ppmv	1 ppmv	1 ppmv
125°C to 20°C	-	80 to 120°C	150°C	80°C
Full pressure*	-	Ambient Pressure	Full Pressure*	70 kg/cm^2
95%	92%	85%	97%	98%
negligible	negligible	-	-	-
-	-	-	70 kg	35 kg
-	-	-	2 kg	2 kg
14,836.95	-	-	13,220.00	13,219.89
256,000 (Claus + tailgas)	256,000 (Claus + tailgas)	256,000 (Claus + tailgas)	289,956.00	+289,955.85
118.08	-	-	-	34.39

* 1 to 25 atmospheres

AIR POLLUTION INVENTORIES

FUEL COMBUSTION SOURCES

by

E. R. Mitchell

ABSTRACT

Since 1955 the Canadian Combustion Research Laboratory (CCRL) has been characterizing pollutants in relation to flame properties. To help relate research to Canadian needs at all times and to help select priorities, an on-going inventory of air pollution from fuel combustion sources was undertaken.

The reliability of such an inventory, which must be calculated, depends upon the accuracy of assumptions regarding the typical performances of flames in all heat process applications and, as well, it depends upon availability of facilities to keep abreast of advances in fuel and combustion technology. For the CCRL, this meant only systematizing flame performance measurements recorded in its on-going program of boiler acceptance testing and fuel efficiency testing, in the field, and appropriate measurements from on-going pilot-scale combustion experiments. The first inventory based on this study was published as Mines Branch Information Circular IC 211, November 1968. It was selected as a guide for OECD study group in 1970 and has been up-dated several times.

PROGRESS DURING 1972

A Study of the Impact of Abatement Strategies

In a recent study, an attempt was made to illustrate the impact of selected abatement strategies on environmental quality in Canada to the year 1980. The abatement strategies selected for the study are those which are often talked about and are tabulated in the following:

(1) reduce the sulphur content of residual oil by 2% below the 1970 level,

(2) reduce total stationary-source NO_x emissions by 25% below the 1970 level by applying low-NO_x flames to 50% of industrial coal, oil, and gas combustion, and

(3) meet the automobile standards laid down in the U.S.A. for 1975 and 1976.

It is pointed out that these assumptions are less precise than any assumptions which CCRL has made about typical flame performance and advances in fuel and combustion technology.

Fuel Consumption Projected to 1980

The availability of premium fuels and their widespread use has encouraged both technological expansion in recent years and a lavish increase of per capita energy consumption. This is illustrated by the fact that, during the 23-year period from 1949 to 1969, total fuel consumption increased at a rate of 4.6% per annum but, in the 5-year period from 1965 to 1970, it increased to an unprecedented rate of 6.1% per annum. This occured in spite of the stabilizing effects of population growing by a constant 2.5% per annum and improved efficiency in fuel use in some sectors. Thus, it is anticipated that fuel consumption from 1970 to 1980 will increase at a rate of 6.5% per annum as shown in Table 1.

Air Pollution Inventory

Based on fuel consumption given in Table 1, inventories of air pollution for 1965, 1970, and 1980 are summarized in Tables 2 and 3. For the years 1965 and 1970 the inventories are based on the known levels of fuel and combustion technology but, for projecting to the year 1980, the abatement strategies tabulated above have been superimposed on the 1970 technology.

Impact of the Selected Abatement Strategies

The impact of the selected abatement strategies is best illustrated graphically as is done in Figure 1. However, to understand the actual burden of this pollution on our air environment, and to help develop a mental model of air-shed pollution burden, an elementary computation was undertaken. In this mathematical model, the air-shed burden in 1965, 1970 and 1980 in lb of pollution per lb x 10^8 of air in a 24-hour period was calculated for a static air-shed of a given capacity with no allowance for either transboundary flow or natural scavenging. CCRL research on atmospheric dispersion indicates that, in a dynamic situation, concentrations of pollution from a large industrial source will be diluted by as much as 3200 at a distance of 16 km downstream. However, this information was not used in the simple mathematical model being discussed. However, the height of air-sheds was varied up to 30,000 ft to assimilate atmospheric mixing. The results, shown in Table 4, indicate that we have a very clean air environment, and that a pollution problem arises with population concentration and, at a local level, in the vicinity of specialized mineral, heat, and chemical processes.

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TABLE 1

Fuel Consumption by Types - 1965 to 1980

Fuel Type		Fuel in Standard Units	Btu x 10^{15}	% per annum Increase
Coal (short tons x 10^6)				
Canadian Bituminous	(1965)	4.978	.124	-10.43[1/]
	(1970)	2.88	.071	- 0.98[2/]
	(1980)	2.6	.065	
Canadian Sub-bit	(1965)	1.864	.030	+13.43[1/]
	(1970)	3.50	.056	+14.37[2/]
	(1980)	13.4	.214	
Canadian Lignite	(1965)	1.796	.024	+12.04[1/]
	(1970)	3.17	.042	+11.13[2/]
	(1980)	9.1	.121	
Canadian Briquettes	(1965)	.021	.0005	-15.40[1/]
	(1970)	.009	.0002	0
	(1980)	.009	.0002	
U.S. Bituminous	(1965)	14.314	.366	+ 4.04[1/]
	(1970)	17.447	.447	+ 3.15[2/]
	(1980)	23.8	.609	
U.S. Anthracite	(1965)	.502	.013	0
	(1970)	.38	.010	0
	(1980)	.38	.010	
U.S. Briquettes	(1965)	.014	.0004	-
	(1970)	.001	neg	-
	(1980)	0	0	
Petroleum Products (bbl x 10^3)				
Light Oil	(1965)	79147	.461	+ 5.12[1/]
	(1970)	101591	.592	+ 5.12[2/]
	(1980)	167382	.976	
Kerosene and Stove Oil	(1965)	18818	.107	+ 0.27[1/]
	(1970)	19074	.109	+ 0.27[2/]
	(1980)	19595	.112	
Diesel Oil	(1965)	35641	.205	+ 5.83[1/]
	(1970)	47313	.272	+ 5.83[2/]
	(1980)	83381	.480	

(continued next page)

Table 1 (cont'd)

Fuel Type		Fuel in Standard Units	Btu x 10^{15}	% per annum Increase
Petroleum Products (bbl x 10^3)				
Heavy Oil	(1965)	78175	.497	+ 7.04 1/
	(1970)	109851	.698	+ 7.04 2/
	(1980)	216903	1.379	
Crude Oil	(1965)	288.1	.002	+ 5.08 1/
	(1970)	366.1	.002	+42.31 2/
	(1980)	12500.0	.070	
Auto Gasoline	(1965)	128542.5	.671	+ 5.41 1/
	(1970)	167314.0	.873	+ 4.50 2/
	(1980)	259833.5	1.356	
Aircraft Gasoline	(1965)	1206.9	.006	+ 4.5 1/
	(1970)	1506.1	.008	+ 4.5 2/
	(1980)	2335.0	.012	
Aviation Turbo Fuel 3/	(1965)	5370.0	.028	+14.1 1/
	(1970)	10370.0	.055	+ 1.6 2/
	(1980)	12155.0	.064	
Gas Fuels (MMcf)				
Natural Gas	(1965)	573016.2	.577	+ 9.9 1/
	(1970)	917440.9	.924	+ 9.8 2/
	(1980)	2336692.1	2.353	
Propane (bbl x 10^3)	(1965)	6321.0	.024	+22.33 1/
	(1970)	17314.6	.066	+ 7.18 2/
	(1980)	34629.0	.133	
TOTAL	(1965)		3.136	+ 6.14 1/
	(1970)		4.225	+ 6.53 2/
	(1980)		7.950	

(Project fuel consumption growth at 6.5% per annum)

1/ % per annum increase from 1965 to 1970.

2/ % per annum increase from 1970 to 1980.

3/ Turbo fuel consumption is computed from Statistics Canada sales data. It is assumed that fuel carried by aircraft is 80% domestic and 20% foreign and, of the total, only 50% is burned in the Canadian air environment.

Note: This table is based on data provided by W. R. Flenniken, Mineral Resources Division, Department of Energy, Mines and Resources, Ottawa, after Statistics Canada.

TABLE 2

FUEL CONSUMPTION BY TYPE AND RESULTING AIR POLLUTION 1965-1980

(Based on Selected Abatement Measures)

Fuel Type		Fuel Consumption per Year			Resulting Air Pollution		
		Btu x 10^{15}	%Total Annual	Annual Rate of Increase,%	Tons x 10^{6}	% Total Annual	Annual Rate of Increase,%
Coal	(1965)	.5	16.1	3.7 2/	.80	2.9	6.6 2/
	(1970)	.6	14.0	5.2 3/	1.10	8.9	5.0 3/
	(1980)	1.0	12.7		1.80	22.5	
Petroleum Products	(1965)	2.0	64.5	5.4 2/	26.30	96.7	-15.8 2/
	(1970)	2.6	62.0	5.4 3/	11.10	90.3	- 5.8 3/
	(1980)	4.4	55.7		6.10	74.4	
Gas (including propane)	(1965)	.6	19.4	10.8 2/	.06	.4	10.8 2/
	(1970)	1.0	24.0	9.6 3/	.10	.8	10.0 3/
	(1980)	2.5	31.6		.26	3.3	
Total	(1965)	3.1	100.0	6.1 2/	27.2	100.0	-14.7 2/
	(1970)	4.2	100.0	6.5 3/	12.3	100.0	- 4.0 3/
	(1980)	7.9	100.0		8.2	100.0	

1/ This is calculated as CO, SO_x,HO and particulates that include HC, soot, and ash.
2/ % per annum increase 1965 to 1970.
3/ % per annum increase 1970 to 1980.

TABLE 3

FUEL CONSUMPTION BY USE CATEGORY AND RESULTING AIR POLLUTION 1965-1980

(Based on Selected Abatement Measures)

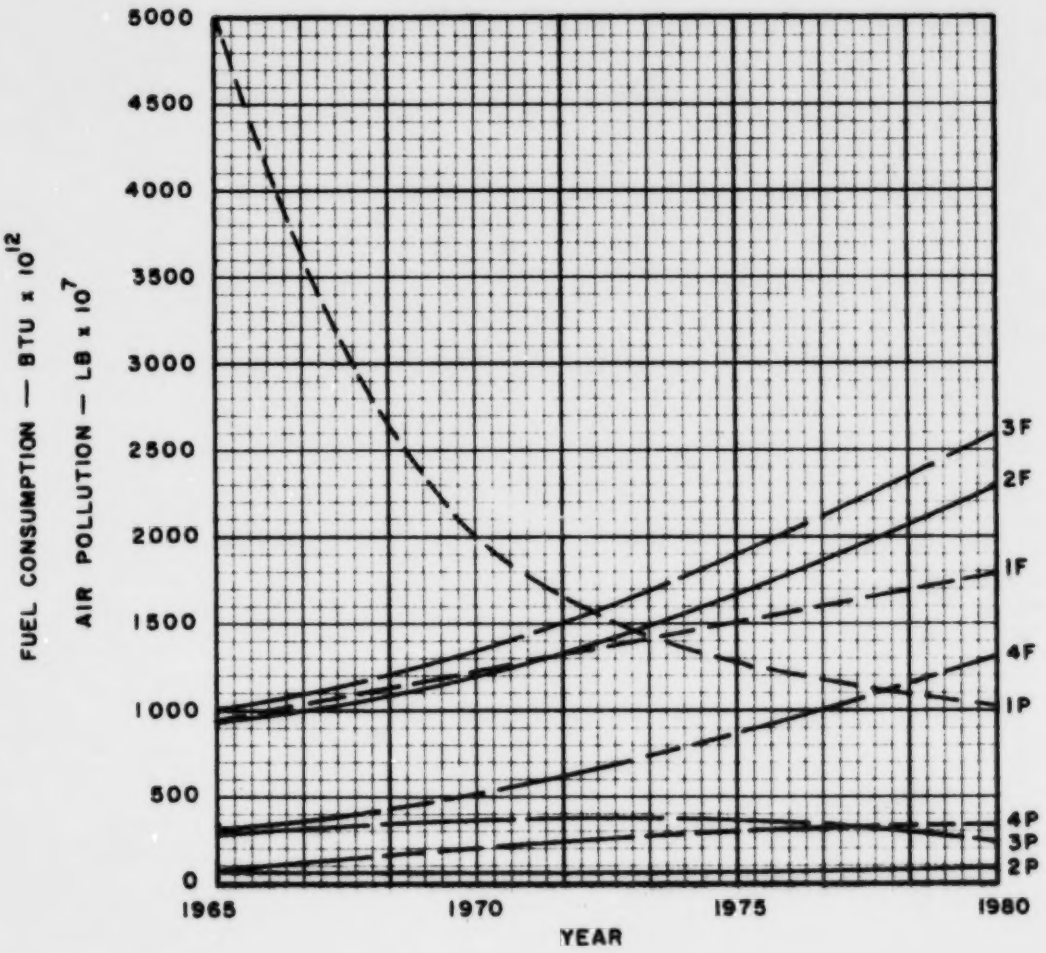
Use Category		Fuel Consumption per Year			Resulting Air Pollution		
		Btu x 10^{15}	% Total Annual	Annual Rate of Increase	Tons x 10^{6}	% Total Annual	Annual Rate of Increase
Residential and Commercial	(1965)	0.9	29.0	5.9 2/	.34	1.1	-1.2 2/
	(1970)	1.2	28.6	6.7 3/	.32	2.4	3.0 3/
	(1980)	2.3	29.1		.43	5.3	
General Industry	(1965)	1.0	32.0	5.4 2/	1.40	5.2	2.7 2/
	(1970)	1.3	31.0	7.2 3/	1.60	13.0	-3.7 3/
	(1980)	2.5	31.6		1.10	13.5	
Thermal Power	(1965)	.3	10.0	10.8 2/	.30	1.1	21.7 2/
	(1970)	.5	11.9	10.0 3/	.80	6.5	7.2 3/
	(1980)	1.3	16.5		1.60	19.6	
Automobile	(1965)	.7	22.6	5.1 2/	24.90	91.5	-18.2 2/
	(1970)	.9	21.4	3.7 3/	9.10 4/	74.0	- 7.4 3/
	(1980)	1.3	16.5		4.23	51.8	
Other Transportation	(1965)	.2	6.5	8.4 2/	.30	1.1	10.8 2/
	(1970)	.3	7.1	5.2 3/	.50	4.1	4.8 3/
	(1980)	.5	6.3		.80	9.8	
Total	(1965)	3.1	100.0	6.1 2/	27.2	100.0	-14.7 2/
	(1970)	4.2	100.0	6.5 3/	12.3	100.0	- 4.0 3/
	(1980)	7.9	100.0		8.2	100.0	

1/ This is calculated as CO, SO_x, NO and particulates that include HC, soot, and ash.

2/ % per annum increase 1965 to 1970.

3/ % per annum increase 1970 to 1980.

4/ Assuming that the automobile will meet emission standards for 1976 as published by U.S. Authorities in the summer of 1971.



Legend

Transportation	Fuel Consumption	1F
	Corresponding Pollution	1P
Residential & Commercial Fuel ..	Fuel Consumption	2F
	Corresponding Pollution	2P
General Industry	Fuel Consumption	3F
	Corresponding Pollution	3P
Thermal Power	Fuel Consumption	4F
	Corresponding Pollution	4P

Figure 1. Fuel consumption by use category and corresponding air pollution trends.

TABLE 4

Pollution Burden of Canadian Air Sheds from Fuel Combustion (Calculated)
Assuming Abatement Measures 1/

		Canada	Industrial Region North of Great Lakes	Toronto	Montreal
Total Air Pollution (not including CO_2) lb x 10^6/yr	(1965)	54914.73	32933.9		
	(1970)	23950.38	14327.2	2302.0	2227.2
	(1980)	16179.08	9717.9	1564.5	1511.1
Pollution Burden 2/					
(a) Static Condition					
Short tons/sq mi/day	(1965)	0,01950	0.4571	-	
	(1970)	0.00849	0.1963	13.14	16.95
	(1980)	0.005	0.1331	8.93	11.50
(b) Static Condition					
lb/10^8 lb air/24 hr, variation with atmospheric mixing height					
2,000 ft	(1965)	.943	21.800	-	-
	(1970)	.410	9.483	634.900	819.027
	(1980)	.278	6.433	431.732	556.938
4,000 ft	(1965)	.485	11.223	-	-
	(1970)	.211	4.882	326.858	421.650
	(1980)	.143	3.312	222.263	286.722
6,000 ft	(1965)	.333	7.704	-	-
	(1970)	.145	3.351	273.973	289.422
	(1980)	.098	2.273	186.302	196.807
8,000 ft	(1965)	.257	5.948	-	-
	(1970)	.112	2.588	173.243	223.485
	(1980)	.079	1.755	117.805	151.970

(continued next page)

TABLE 4 (cont'd)

		Canada	Industrial Region North of Great Lakes	Toronto	Montreal
$lb/10^8$ lb air/24 hr, variation with atmospheric mixing height					
10,000 ft	(1965)	.212	4.900	-	-
	(1970)	.092	2.130	142.686	184.066
	(1980)	.062	1.446	97.026	125.165
15,000 ft	(1965)	.152	3.510	-	-
	(1970)	.066	1.528	102.277	131.938
	(1980)	.045	1.036	69.548	89.718
25,000 ft	(1965)	.010	2.432	-	-
	(1970)	.046	1.058	70.842	91.386
	(1980)	.031	.718	48.172	62.142
30,000 ft	(1965)	.094	2.176	-	-
	(1970)	.041	.947	63.368	81.746
	(1980)	.028	.642	43.090	55.587

1/Abatement Measures:

(1) Reduce sulphur content of residual oil by 2% below 1970 level.

(2) Reduce stationary-source NO_x emission by 25% below 1970 level by applying low-NO_x flames to 50% of industrial coal, oil, and gas combustion.

(3) Meet the automobile emission standards published in the U.S.A. for 1975 and 1976.

2/Computed by Dr. H. Whaley, Canadian Combustion Research Laboratory and based on preliminary pollution data that is subject to minor revision. The computations are intended to illustrate the order of magnitude of the impact of fuel combustion on the air environment in relation to population concentration.

CCRL FUEL EFFICIENCY PROGRAM

by

A.C.S. Hayden

ABSTRACT

The Fuel Efficiency Program of the Canadian Combustion Research Laboratory (CCRL) has three basic objectives:

1) to provide a basis for the analysis of the chemistry of flames, resulting in the reduction of pollutant formation at the flame;
2) to provide a means of conserving Canada's resources by obtaining the highest possible conversion efficiency from fuel to useful heat;
3) to provide a reliable and comprehensive evaluation of state-of-the-art industrial burner and furnace designs in order to determine future directions for combustion research.

Work has proceeded along three fronts in 1972:

1) advanced methodologies for performing tests, evaluating their results, and predicting performance;
2) field testing of industrial installations using advanced measurement techniques;
3) laboratory evaluation and consulting with respect to industrial equipment and installations.

PROGRESS IN 1972

Advancing Methodologies

Advanced measuring equipment for the automated sampling and continuous analysis of the flue gases was put into extensive use in field testing in 1972, particularly with regards to boiler acceptance tests. For

the tests performed in the first half of the year, laboratory-quality instruments were used; specifically, two infra-red analyzers monitored CO_2 and CO, and a paramagnetic analyzer monitored oxygen, all equipped with comparable-quality recorders. These continuous analyzers allow for immediate detection of any change in conditions re efficiency or increased pollutant emission during the test. As well, they provide an extremely accurate gas analysis while freeing one test member for other duties. During the summer, instruments operating on the same principles, but designed primarily for field usage, were purchased along with more-portable recording equipment. After some initial problems, this set of instruments promises to be most satisfactory.

The data reduction procedure for the determination of the efficiency of heat producing equipment using data obtained during boiler acceptance tests has been totally automated on the digital computer. The program includes complete programming of the steam tables as well as the heat balance - heat loss calculations required by the ASME test procedure. This has resulted in substantially speeding up the determination and reporting of test results, while ensuring accurate calculations.

A comprehensive digital program now permits the analytical prediction of the effects of excess air, preheat, recirculation, oxygen, and/or nitrogen enrichment/deletion and fuel composition on the adiabatic flame temperature, and on the amount of pollutants produced at the flame, particularly NO, SO_2, SO_3, and CO. The program allows the determination of optimum conditions for minimum pollutant formation. Preliminary studies have already been done to attempt to show the effects of preheating the combustion air and of increasing its relative oxygen concentration. Sample results for No. 2 fuel oil are shown in Table 1.

TABLE 1

Effect of Preheat and Oxygen Level on Adiabatic Flame Temperature While Burning No. 2 Fuel Oil

Oxygen Level	Adiabatic Flame Temperature, °F Preheat				
	100°F	500°F	1000°F	1500°F	2000°F
Air	3601	3637	3682	3733	3788
25%	3832	3868	3907	3949	3997
30%	4021	4049	4093	3138	4190
35%	4168	4201	4242	4280	4325
40%	4280	4307	4343	4384	4427
45%	4364	4393	4427	4465	4507
65%	4579	4604	4641	4683	4724
95%	4760	4787	4823	4863	4904

Boiler Acceptance Tests

These tests, also described as combustion performance tests or heat balance tests, have been done on industrial installations as part of this program. They follow the standard ASME test procedure for steam boilers and high-temperature water generators, with modifications predicted by the experience of CCRL staff and are designed to maximize the efficiency of the combustion system and of the entire unit and to minimize air pollution. The tests provide the plant with a permanent record of operating parameters to achieve these results, while giving CCRL an appreciation of present design.

In 1972, 100 tests were done on 22 boilers in 7 different federal government heating plants. Some of the tests were on units which originally had been coal-fired but had been converted to fire oil or natural gas; the others were on completely new units. Flue gas analyses were performed with the instrument set mentioned previously. Where there was a potential for sulphuric acid corrosion due to SO_3 or acid soot in the flue gas, acid dewpoint measurements were also taken, using a BCURA meter-probe, and particulate concentration was determined by a stainless steel cyclone unit. The tests involved firetube and water tube boilers and high-temperature water generators, firing No. 2 fuel oil, No. 6 fuel oil, or natural gas in a range of combustion systems. Table 2 presents a summary of the results obtained over the past year.

Combustion Handbook

As an aid to industry, plant operators, and consultants, a combustion handbook has been developed by CCRL staff. The handbook provides a quick, accurate means of designing new combustion systems and evaluating existing operations, while maximizing fuel efficiency and minimizing air pollution. The volume on oil was published previously. Its acceptance has been almost universal and it has received considerable acclaim from all concerned.

TABLE 2

Summary of Results of Boiler Acceptance Tests Conducted in 1972

Class	Type	Combustion System	Fuel	Excess Air Firing Rate			Efficiency Firing Rate		
				Low	Medium	High	Low	Medium	High
High Pressure Steam Boiler	Watertube-Converted	Steam Atomizing	#6 Fuel Oil	76.7	25.2	18.5	77.2	81.4	80.1
"	" "	" " +economizer	"	55.8	27.2	23.2	85.0	84.7	83.1
"	" "	" "	#2 Fuel Oil	34.8	26.5	15.6	80.9	81.6	81.1
"	" "	Spud	Natural Gas	46.0	11.4	6.6	75.8	78.8	78.2
"	" New	Steam Atomizing	#6 Fuel Oil	38.7	28.9	18.7	81.2	82.2	80.3
"	" "	" "	#2 Fuel Oil	52.5	13.3	14.0	79.0	82.3	79.6
"	" "	Spud	Natural Gas	41.0	12.0	12.5	76.1	77.8	75.9
"	Firetube "	Air Atomizing	#2 Fuel Oil	130	40.5	17.0	74.5	81.1	82.9
"	" "	" "	Natural Gas	42.0	8.0	7.0	74.7	79.9	80.4
Hot Water Generator	Watertube-Converted	" "	#6 Fuel Oil	168	85.5	28.0	70.0	77.0	78.5

The volume dealing with gases is now complete, and is awaiting publication. The third volume, on coals, is almost finished. The latter will include all Canadian coals and those American coals used in commercially significant quantities. These three handbooks are now also being prepared in metric format for international as well as future national requirements.

Additive Evaluation

CCRL was asked to determine the effects of a commercial manganese-based fuel additive on the potential for corrosion, due to condensed sulphuric acid and acid soot, and to evaluate the air pollution potential in a particular government heating plant. To this end, CCRL staff conducted tests on the plant before and after the addition of the additive. The tests showed that, although corrosion potential and emissions were reduced to a degree, the problems still did exist. It was recommended that either the dosage rate of the present additive be increased (at a high cost) or, preferably, another additive, this one magnesium-based, be used instead.

Industrial Burner Evaluation

During the past year, advice has often been sought from CCRL on how to resolve burner problems in existing government installations. In one case, problems of flame instability on natural gas firing and poor atomizing on oil firing were encountered in a new boiler. After preliminary tests, CCRL gave detailed recommendations on how to correct the problem by modification of the existing design. All recommendations were followed, and the subsequent acceptance tests showed most satisfactory results, with high fuel efficiencies and negligible pollutant emission.

In the second case, the laboratory was approached by National Defence for aid in determining the solution to combustion problems encountered in a gas turbine engine. In particular, the combustors in the engine were

generating large amounts of soot, up to the point where the exits from the combustion chambers were becoming blocked after only a short running time, necessitating shutdown. It was feared that large pieces of this solid carbon deposit could break off and fly into the turbine blades causing permanent damage. The manufacturer initially refused to acknowledge the problem, but, after CCRL was consulted, a different design of nozzle and combustor can was provided. The problem was considerably but not completely alleviated.

The two burners and cans are now undergoing aerodynamic and combustion tests at CCRL, with the hope of modifying one or both to obtain a burner which gives much more efficient and cleaner combustion than either system in its present form.

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FLAME RESEARCH

BLUE FLAME COMBUSTION

by

T.D. Brown

ABSTRACT

Current designs of burners for residential heating incorporate a flame holding device at the end of the burner gun. The flames from these burners are luminous which indicates the formation of soot in the flame which, subsequently, either may be deposited on the gas side surfaces of the appliance leading to a deterioration in performance or may be emitted to the atmosphere as a particulate pollutant.

The blue-flame burner shows a greater rotational component in the combustion air flow and the consequent increase in flame recirculation leads to fuel vaporization before combustion and to non-luminous combustion.

PROGRESS IN 1972

The use of rotating jet flows in flames is known to generate a central core recirculation which constitutes a well-mixed zone of combustion products and acts as a source of heat and reactive species in the centre of the jet near the burner exit. For one type of swirl generator (the vane swirler), the central mass recirculation can be predicted from the geometry of the swirl generator. The principle followed in prototype design was to generate a rotating flow with central and external flame recirculation from an annular vane swirler surrounding a conventional narrow-angle pressure jet atomizer. A series of vane swirlers designed for insertion into a 2-in.-diameter blast tube were constructed.

It was observed that, as the degree of rotation (swirl) of the input air was increased, the characteristic of the flame changed from luminous to non-luminous and that both the smoke emission and the nitric oxide emission decreased with no significant emissions of carbon monoxide or gas-phase hydrocarbons.

The range of smoke-free operation of the prototype burners increased as the swirl increased and led to smoke-free combustion at progressively lower levels of excess air. The lowest nitric oxide emissions were all measured at the highest degree of swirl.

It has been possible to plot a pressure drop flame luminosity diagram which indicates that the blast tube pressure necessary to generate blue flame combustion is approximately twice that used in conventional systems.

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FLAME RESEARCH

LOW NO_x FLAMES

by

T.D. Brown

ABSTRACT

Nitric oxide is the most important oxide of nitrogen formed in modern high-temperature boilers and, after emission, it will react with atmospheric oxygen to produce toxic nitrogen dioxide. Atmospheric photochemical reactions between nitrogen oxides, oxygen, and hydrocarbons produce smog which contains the lachrymatory peroxy-acetyl nitrates. In high concentrations, the smog product damages vegetation and causes human respiratory difficulties.

The objectives of this research program are to quantify some relevant combustion performance parameters that can be controlled or manipulated so as to minimize the formation of nitric oxide in flames.

The formation of nitric oxide (NO) from atmospheric nitrogen in high-temperature systems has been exhaustively examined by previous investigators and a rate expression of the form

$$\frac{d(NO)}{dt} = k\, e^{\frac{-E1}{RT}}\, (O_2)^{1/2} (N_2) - k_2\, e^{\frac{-E_2}{RT}}\, (NO)^2\, (O_2)^{-1/2}$$

is generally taken to represent the progress of the reaction. It is apparent that reductions in temperature and oxygen partial pressure (excess-air level) will both contribute to a reduction in the formation of nitric oxide in flames. The Canadian Combustion Research Laboratory

has focused its attention on these two variables in a series of experiments designed to study their relative importance in the control of nitric oxide formation in flames.

PROGRESS IN 1972

Methods of control of the formation of nitric oxide in operating systems that are based on the kinetic equation above are:

(1) low excess air combustion,

(2) decreased combustion intensity, and

(3) external flue gas recirculation.

The effect of decreasing the combustion intensity is to reduce the maximum temperatures achieved in the flame. This is generally achieved by a reduced fuel consumption in the same combustion chamber volume and corresponds to a decreased load on the system; the usefulness of this technique is obviously limited.

The effect of introducing externally recirculated flue gas which is largely (95%) inert at temperatures of 400°F into the combustion process is to increase the thermal load on the fuel because this gas must be reheated to flame temperatures. The effective flame temperature is lowered, so the rate of all reactions, including those leading to nitric oxide production, is reduced; the mass throughput is increased and residence times in reaction zones are decreased. These factors all contribute to reduction of the nitric oxide emission.

A series of experiments investigating the effect of external flue gas recirculation on the emission of nitric oxide from the combustion of liquid fuels have been carried out in a pilot-scale 16-gph (US) boiler.

Low-excess-air combustion has been shown to be less effective than external flue gas recirculation in reducing the NO emission.

The emission of $(NO)^+$ in lb/1000 lb fuel could be related to the recirculation ratio R and the emission without recirculation (NO) by a general linear equation:

$$\frac{(NO)}{(NO)} = 1 - A R^* \quad (0 < R < 0.5)$$

$$R^* = \frac{\text{Mass Recirculated}}{\text{Mass of Fuel + Air + Recirculated Products}}$$

Results obtained using a crude oil fuel (nitrogen content = 0.2%) indicated that the value of A is a constant (3.3) for all excess air levels at high combustion intensities (80,000 Btu/ft^3/hr). At lower combustion intensities (60,000 Btu/ft^3/hr), the value of A was a function of the excess air level and was generally lower than at the high combustion intensities.

It has been observed that the introduction of external flue gas recirculation, under limiting low-excess combustion conditions (production of carbon monoxide), gave improved combustion and eliminated the carbon monoxide at recirculation ratios (R) above 0.15. This has been attributed to the increase in burner momentum and the consequent improvement in air-fuel mixing.

The results were considered to confirm the view that flame temperature rather than excess air level was the dominant factor in the production of nitric oxide in the combustion process.

In conjunction with the experimental study, a model of the effect of flame variables on the production of NO has been developed to establish how the nitrogen content of the fuel affects the end product emission. No data was available to describe the reaction of fuel nitrogen compounds with oxygen and it has been necessary to assume a kinetic expression based

on field experience. The reactions were generally thought to occur rapidly at lower temperatures than those necessary for atmospheric nitrogen fixation; this implied a lower activation energy than the atmospheric nitrogen reaction with a relatively high pre-exponential constant. The results from this model give indications of trends that will occur in practice but they cannot be used to give quantitative predictions.

The initial results from the model showed that:

(1) There was an optimum excess air level for maximum NO production from both atmospheric nitrogen and fuel nitrogen. This prediction has been confirmed experimentally.

(2) The effect of introducing external flue gas recirculation was to reduce the NO formed from atmospheric nitrogen in preference to the NO formed from the fuel nitrogen.

External flue gas recirculation is therefore a total control measure for the combustion of nitrogen-free fuels. It is an effective control measure for reduction of the nitric oxide formed from atmospheric nitrogen during the combustion of nitrogen-bearing fuels but has only a a limited effect on the formation of nitric oxide from the fuel nitrogen.

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FLAME RESEARCH

RESIDENTIAL BURNERS

THE OIL HEATING ASSOCIATION OF CANADA

CLEAN AIR PROGRAM

by

T.D. Brown

ABSTRACT

A test facility, for the assessment of residential oil burners in relation to atmospheric pollution potential and thermal efficiency has been constructed. The facility allows measurement of the conventional combustion parameters, trace amounts of gas, and noise.

PROGRESS IN 1972

During 1972 the Oil Heating Association of Canada placed a contract with the Canadian Combustion Research Laboratory to investigate the pollutant emission characteristics of current designs of Canadian residential burners.

The program of the tests, which commenced in November 1972, includes measurements on:

a warm-air furnace with stainless-steel combustion chamber

a warm-air furnace with refractory combustion chamber

a hot water boiler with refractory combustion chamber

a hot water heater.

The test program reported at the previous emvironment seminar has led to the nomination of five burners to be tested in each of these units under different draught and thermal-input conditions. It is anticipated that the test program (duration one year) will produce basic

information, on the performance of burners under start-up, steady running, and shutdown conditions, that can be used as a reference against which new systems may be compared.

FLAME RESEARCH

THE COMBUSTION OF COAL-IN-OIL SLURRY

by

G.K. Lee and T.D. Brown

ABSTRACT

A coal-in-oil combustion research project was initiated in December 1971 with technical support from Ontario Hydro and financial assistance from the winter works program through the Metals Reduction and Energy Centre. The purpose of the research was to demonstrate the technological feasibility of burning coal-in-oil slurries as a fuel for steam raising.

A pilot-scale hydraulic system for blending and pumping coal-in-oil slurries was designed and installed and a commercial, low-pressure, air atomizing, oil burner was modified to burn this type of fuel.

A series of combustion trials were carried out to determine the combustion properties of two Canadian coals when burnt as a 35% slurry in No. 2 oil.

PROGRESS IN 1972

The coals used in the combustion trials were a western Canadian lignite and a bituminous coal reject. The bituminous coal reject contained more than 60% fusinite and semi-fusinite which profoundly restricted its ignition and combustion.

Static sedimentation tests indicated that a conventional pulverized coal grind (70% less than 200 mesh) would give a suspension

that did not settle appreciably during a series of six-hour combustion trials. Accordingly, batch quantities of the coal-in-oil suspension were continuously stirred and circulated to eliminate fuel separation in the handling system during the trials.

The experimental combustion trials indicated that complete combustion of the lignite was achieved without modification of the system. The degree of burn-out of the coal component was exceptionally high, between 96 and 99%; this was higher than the level achieved when the same fuel was burnt alone as pulverized fuel and represents a significant improvement over current industrial practice where burn-out between 80 and 90% of the coal is usual.

The degree of burn-out of the inert bituminous coal was generally between 40 and 60% with the most complete combustion being achieved at the highest excess air level. This degree, of burn-out was higher than that achieved when the coal was burnt alone as pulverized fuel.

It was concluded that a petrographic examination of the coal will provide a rapid preliminary classification of the suitability of coals for blending with oil to produce a coal-in-oil fuel.

The results indicated clearly that a coal-in-oil fuel can be successfully burnt in conventional combustion equipment and that the combustion efficiency of this fuel is higher than pulverized coal alone. The principal factors that have yet to be optimized are:

(a) the size distribution of the coal in the fuel,

(b) minimum excess air levels, and

(c) the influence of crude and residual oil carriers on combustion performance.

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FLAME RESEARCH

NEXT GENERATION OF BURNERS

by

F.D. Friedrich

ABSTRACT

The next generation of burners will be characterized by minimum pollution emission. They will produce virtually neither CO, unburned hydrocarbons, nor soot, but, at least while burning oil or gas, they will operate with excess air in the range of 3%, equivalent to 0.6% O_2 in the flue gas. At the same time, NO emission will be reduced by at least 50% to between 45 and 200 ppm depending upon furnace conditions. To maintain consistently low NO, it is likely that forced recirculation of combustion gases to the burner may be added. It is anticipated that this high level of performance will be achieved by means of combustion air at high pressure (15 in. of water or more) coupled with scientifically selected methods for generating high levels of turbulence. It is expected that flames will be more transparent than in the past; some oil flames will be blue.

The present well-proven technology for fuel oil atomization and coal pulverization will probably be used in the next generation of burners.

Flame research in recent years has shown that the process of combustion is dominated by the fluid mechanics of the system rather than by chemical kinetics or heat transfer. This research has also led to the development of reliable techniques for measuring flame aerodynamics and thermodynamics. Thus, the diffusion mechanism can now be controlled in quantitative terms by means of swirl, or shearing jets, and it becomes useful to develop swirl parameters.

PROGRESS IN 1972

At the Third Mines Branch Seminar on Environmental Improvement, some predictions were made as to the performance characteristics of the next generation of burners and the difficulties to be expected in achieving them were briefly outlined. It is convenient to summarize these anticipated characteristics here, as follows:

1) operation at very low excess air;
2) negligible emission of unburned hydrocarbons, CO, and SO_3;
3) substantially reduced emission of nitrogen oxides.

The first two of these characteristics can be achieved by intense mixing, which, in turn, can be accomplished with conventional hardware using combustion air at relatively high pressure. The formation of nitrogen oxides, however, depends on a number of factors not yet fully understood. It is now clear that reducing the flame temperature has a major influence in reducing nitrogen oxide formation. Other important factors appear to be the level of excess air and the concentration of organic nitrogen in the fuel. Furthermore, recent work at CCRL with No. 2, No. 6 and crude oil has demonstrated that nitrogen oxide formation can be significantly reduced by externally recirculating flue gas to the combustion air stream. The dominant mechanism here seems to involve a reduction of flame temperature by diluting the combustion air with inert combustion products.

In the last quarter of 1972, work began on a CCRL project intended to throw further light on the first-order parameters influencing the formation of nitrogen oxides in flames. The initial aims of the project are as follows:

1) to study the effect of excess air level and fuel-source nitrogen on the formation of nitrogen oxides in the flame;

2) to determine to what extent combustion aerodynamics can be used to control flame temperature by means of recirculation into the flame envelope without employing the more cumbersome process of external flue gas recirculation.

With respect to the first of the foregoing aims, it should be explained that theoretical analysis suggests that, as combustion air is increased from the stoichiometric level, nitrogen oxide level should increase up to a certain point and then decrease as the excess air reduces flame temperature by dilution. This phenomenon has never been observed in a flame, but it could easily be masked by incomplete mixing. The second aim could be more simply described as an attempt to build a blue-flame burner.

Thus, both aims require a burner that has a high mixing intensity. Such a burner is not commercially available in a size to suit the CCRL tunnel furnace (2 million Btu/hr input), so it has become necessary to build one, and the efforts of the past few months have centred on this objective. At the time of writing, a burner employing conventional hardware but fairly sophisticated aerodynamics had been fabricated, and initial trials gave promising results. A high mixing intensity has been achieved, and it appears likely that a suitable design of combustion chamber will result in a blue flame while burning No. 2 furnace oil. Variation in fuel nitrogen content can be obtained by burning kerosene, which contains approximately 100 ppm nitrogen, and No. 2 furnace oil, which contains approximately 700 ppm nitrogen. Nitrogen could be further increased by adding appropriate organic compounds to the fuel.

It is planned to do this work in the first few months of 1973. It may then be decided to study further the effect of flame temperature on nitrogen oxide formation by using preheated combustion air as a variable.

PLUME DISPERSION RESEARCH

by

H. Whaley and G.K. Lee

ABSTRACT

This continuing research program, initiated in 1969 with the active collaboration of industry and both federal and provincial government agencies, is to obtain reliable information on plume rise and dispersion from tall stacks under conditions specific to Canada. In this program the influence of meteorology, topography, and climatology on the behaviour of hot plumes is being measured by aerial probing with priority being given to regions that are potentially prone to severe ground-level pollution. Six geographic regions have been selected for study and for convenience they have been defined as:

1) land adjacent to large bodies of water;
2) prairie;
3) hilly terrain;
4) river valleys;
5) foothills; and
6) arctic or sub-arctic.

At the time of writing eight studies had been conducted in five of the regions and a preliminary evaluation of the field data confirms that information obtained in other countries cannot be applied with confidence in computations of stack height and plume impingement for many parts of Canada. Preparations are now underway for two plume dispersion studies to be made in February and May of 1973.

PROGRESS IN 1972

Plume Sources Studied

During 1972 four plume dispersion studies were made in Alberta on behalf of Gulf Oil Canada Ltd. and with the co-operation of the Alberta Energy Resources Conservation Board and the Atmospheric Environment Service, Environment Canada. All of the plumes studied were emitted from tall stacks at sour-gas processing plants located in sparsely populated areas near Pincher Creek, Strachan, Rimbey and Nevis.

The stacks at the Pincher Creek and Strachan gas plants provided original dispersion data for foothill country during "Chinook" and "down slope" winds respectively, while those at the Rimbey and Nevis gas plants provided information on the effects of flat tree-covered terrain and of a bend in a steep river valley on plume behaviour.

Seven restricted reports, describing eight plume dispersion studies were completed during the year and circulated to the agencies which participated in each study. In addition, two scientific papers, now in preparation, will be submitted to Atmospheric Environment and the International Union of Air Pollution Prevention Associations for publication.

Data Reduction

Data reduction has been improved both in speed and accuracy by the use of a digitizer in association with a desk-top computer. This system has enabled direct translation of strip-chart data into contour maps of spatial SO_2 distributions in the atmosphere. All programs have been debugged and for the first time since the plume dispersion research project commenced, data reduction has caught up with data acquisition, despite four surveys being conducted in April 1972, as mentioned earlier.

Data Evaluation

It has been evident since the first survey in 1969 that the quality of data obtained during this program, justified much improved data evaluation techniques over those found in the literature. The determination of plume parameters has been very inaccurate, mainly due to the lack of definitive data.

In the same way that the digitizer system was utilized for improving data reduction techniques, a procedure has been devised for determining plume dispersion parameters which eliminates the subjective selection of partial or incomplete data for the same purpose. The equations of pollutant mass flow have been taken and reduced to finite-difference form, from which it becomes very simple to derive plume spread parameters:

1. σ Values

As mentioned at the last seminar, the basic plume dispersion model is Gaussian in nature, usually taking the form of a bivariate distribution in the cross wind and perpendicular dimension (Y, and Z). The classical Gaussian profile is completely defined by its standard deviation σ and hence it is clear to see that this will represent an important parameter for the cross section of a real plume. By an input of digitized information from the reconstructions of cross wind SO_2 isopleths, it is possible to determine the bivariate σ values (σy and σz) also the co-ordinates of the pollutant centre of mass flow $\bar{Y}\bar{Z}$. These parameters are important in fixing the spatial location of the plume and to determine such parameters as axial distance ($\bar{X}$) and plume rise ($\Delta\bar{Z}$). To continue the line of thinking which was reported at the last seminar, it may be possible to relate departures of real plume profiles from the classical Gaussian

model by an extension of this evaluation technique.

2. Selection of Chimney Height

As more information is gathered and evaluated it is becoming clear that the behaviour of plumes can be associated with the type of climatic region in which the source is situated. The CCRL objective is to determine sufficient reliable data on these climatic regions that stack height can be selected and plant sites chosen so that no detrimental effect on the surrounding environment will ensue.

NOMENCLATURE

X,Y,Z - Three-dimensional cartesian co-ordinate system representing down-wind distance, cross-wind distance, and height respectively.

$\bar{X}$ - Axial distance down-wind.

$\bar{Y},\bar{Z}$ - Co-ordinates of centre of pollutant mass flow in the cross-wind and vertical dimensions respectively.

$\bar{\Delta Z}$ - Plume rise - height of plume axis above the stack top.

σ - Standard deviation of SO_2 distribution.

$\sigma y, \sigma z$ - Standard deviation of SO_2 in the cross-wind and vertical dimensions respectively.

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In addition three restricted reports of other joint studies have been published as Divisional Reports. These are not yet available for general circulation.

METHODS FOR THE REMOVAL OF SULPHUR DIOXIDE FROM WASTE GASES

by

H.P. Dibbs

A detailed review of methods for the removal of sulphur dioxide from the waste gases emitted from the combustion of sulphur-containing fuels and from the smelting of sulphide ores has been published as a Mines Branch Information Circular (IC 272). This report covers the literature up to late 1971. The methods were classified into a number of groups based upon either the removal technique or on the absorbent employed in the removal process. From the technical and the economic viewpoint, it is apparent that the chief problem in sulphur dioxide abatement is the treatment of waste gases containing low concentrations of sulphur dioxide. Although a large number of processes have been proposed for these gases, none have as yet been proven on a commercial scale. However, approximately twelve potentially viable methods are undergoing, or are about to undergo, full-scale testing, using techniques which recover sulphur (or a sulphur-containing product) either for sale or for discard. In North America, scrubbing with a lime/limestone slurry is undergoing extensive development and is favoured as the short-range solution for the treatment of flue-gases from power stations and of weak smelter gases. This method gives a sulphur dioxide absorption product which is discarded.

REMOVAL OF PARTICULATES FROM HOT GASES

by

R.D. Warda

ABSTRACT

The purpose of this program is to assess the problem of particulate emissions produced by pyrometallurgical sources and to investigate new methods of abating these emissions. The study of particulate emissions was one aspect of a detailed study of cupola emissions which has yielded useful information not only on particulate emissions but also on gaseous emissions, on cupola sampling methods, and on the performance of multi-cyclone dust collectors on cupolas. The study of new methods of abating particulate emissions has been concerned with the use of packed bed filters for the removal of particulates directly from hot pyrometallurgical process gases. The results of this investigation have indicated that the use of packed bed filters consisting of granular charge materials is feasible not only for abating particulate emissions from pyrometallurgical furnaces such as cupolas, but also as combined filter-preheater in processes such as coke ovens.

PROGRESS IN 1972

During 1972, the sampling methods used and the data collected during the 1971 cupola emission survey were analyzed statistically and compiled in the form of two papers, the summaries of which follow.

1. "A Method for Sampling Cupola Emissions"

Variations in cupola emissions between foundries are of such magnitude and significance that neither specific nor general emission measurements can be applied with any confidence to any foundry other than the one at which the measurements were taken. Variations within a foundry

arise from a number of sources and are of such magnitude that testing should be conducted for several days if reliable results are to be obtained. Variations in stack gas temperature and velocity during a test necessitate the continuous measurement of these parameters. A relatively simple and robust particulate sampling train similar to the one described in the paper provides ample precision for cupola stack testing. Deviations from isokinetic sampling conditions as great as 20 per cent do not cause significant variations or bias in the particulate emission rate measurements. The reliability of the gas analysis equipment and methods used for measurement of CO, CO_2, and O_2 was confirmed by the excellent agreement obtained from materials balance equations. The method of grab sampling for NO_x and SO_x should be improved or changed to a continuous method to provide greater precision and accuracy. The precision and accuracy of sampling practices are of limited value unless emission measurements are correlated with concurrent observations of cupola charging and operating procedures.

2. "A Detailed Study of Cupola Emissions"

This paper describes in detail all gaseous and particulate emission parameters relevant to the problem of abating cupola emissions and correlates these parameters with the design and operation of the individual cupolas tested. A significant fraction of the material presented in this paper was prepared for and presented at the Third Mines Branch Seminar on Environmental Improvement in March 1972. Since that presentation, size analyses have been extended, using optical and electron microscopy, to the sub-micron particle range and X-ray diffraction and fluorescence analyses have been completed for dust in all size ranges.

Results of the size analyses indicate that there is very little dust in the 25.0 to 1.0-micron range but there are large and variable amounts of dust in the 1.0 to 0.10-micron size range (from 3.2 to 25 per cent

of the total dust was sub-micron). Variations in charge materials and charging practices affected not only the dust production rates but also the size distribution. All sub-micron dust was spherical and resulted from the condensation and/or oxidation of metallic vapours generated in the melting zone. The amount of fume produced per ton of metal melted did not vary widely, except for foundries melting primarily purchased low-quality domestic scrap which produced significantly more fume. The reason for the wide variation in the fraction of the dust which was fume resulted from the large variations in the amounts of coarse dust emitted per ton of metal melted. This coarse dust was found to be transmitted by rather than generated within the cupola. The nature and origin of this dust was confirmed by the institution of changes in charging practice at certain foundries which not only reduced the dust emission rate, but significantly reduced the fraction of coarse dust.

Fluorescence analyses indicated that the chemical composition of the dust varied not only between foundries, but with its particle size. Variations between foundries could again be traced to either charge materials or charging practices. One foundry, which used an electromagnetic charging device, had an extremely high iron content in the coarse fractions of the dust. The foundries which charged low-quality domestic scrap had heavy emissions of lead and zinc (1 to 2 lb/ton), most of which was contained in the sub-micron fume.

Diffraction analyses indicate that the compounds in which the principal elements are found do not vary significantly either between foundries or between size fractions coarser than 1 micron. In the coarse dust, the principal compounds are αSiO_2, Fe_2O_3, Fe_3O_4 and refractory silicates. A significant fraction of the fine dust was non-crystalline,

with Fe_2O_3, Fe_3O_4 and PbS, Pb_3O_4 and ZnO as the principal crystalline components.

One of the foundries which participated in the original emission survey suggested that a second survey be done in 1972 to determine the reduction in emissions resulting from the implementation of suggestions made by PMD personnel during the first survey as well as from the installation of a multi-cyclone dust collector. The preliminary results of the second survey, have been reported in Test Report PM-72-22 and show 97 per cent collection efficiency of the plus 25-micron fraction of dust. The changes in charging practices recommended were found to have been highly effective.

3. "Effluent Abatement Using Packed Beds"

During 1972, work on this project has consisted of the design and construction of a cupola simulator and the performance of a large number of tests to determine the permeability and collection efficiency of various granular materials. Changes in these parameters resulting from the accumulation of dust in the bed have also been investigated. For all materials tested - glass beads, steel shot, graphite, coke, coal and iron ore - the relationship between the pressure drop (ΔP) across the bed and the air flow rate (Q) is defined by the equation

$$\Delta P = KQ^n$$

where K varies linearly with bed height and is a complex function of bed porosity, and n is a constant with an average value of 1.7.

Variations in collection efficiency and pressure drop during dust accumulation in the bed depend primarily upon the pore size and porosity of the bed. For coarse beds (all particles plus 20 mesh), the efficiency and rate of increase of pressure drop are initially low, but increase rapidly as the dust accumulates within the bed and reduces the porosity. Sufficiently fine beds (containing significant amounts of 20 to 70-mesh particles, have

high (>99 per cent), relatively constant, efficiencies and commensurately high rates of increase of pressure drop.

Certain beds which have been shown to combine high efficiencies (>99 per cent) and acceptable pressure drops (≈20 in. W.G.) are considered feasible, and applications to industrial processes are being considered. In this regard a coal preheating and filtration process has been designed, the details of which have been filed both as a Report of Invention and as Internal Report PM-R-72-11.

FUME CONTROL IN REFINING SECONDARY ALUMINUM

by

L.V. Whiting and J.O. Edwards

ABSTRACT

Experiments were conducted on the chlorine treatment of aluminum for the removal of magnesium.

These have demonstrated the mechanism by which the reaction is accomplished and have shown that the desired objective can be achieved without the evolution of fume of any kind.

PROGRESS IN 1972

Chlorine is widely used in the aluminum industry for cleaning melts of oxides and dross, degassing melts and refining secondary scrap to reduce the magnesium content. These are accomplished by bubbling chlorine through the melt. The gaseous products, i.e., excess chlorine, HCl and volatile $AlCl_3$ (which hydrolyses to HCl and Al_2O_3), must be collected. Because of the large quantities of chlorine used and hence the potential for generating fume, the magnesium reduction step is of particular concern.

Canadian secondary aluminum smelters reclaim about 50 million pounds of aluminum scrap a year (1), much of it containing about 0.5% magnesium. The scrap is refined for use mainly in die casting alloys with a chemical specification requiring less than 0.10% magnesium. Most secondary aluminum smelters are located in cities and, as an example of the contamination potential, 60,000 lbs of scrap, about 60% of it originally containing 0.7 to 0.8% Mg, would typically be refined by 330 lb/hr of chlorine for between 2 and 4 hr. Because stoichiometrically 1 lb Mg combines with 3 lb Cl_2, this

represents a chlorine consumption of anywhere from the minimum to twice the amount of chlorine necessary to reduce the magnesium from 0.45% to the required 0.1% max.

An adequate explanation of the reactions involved has not appeared in the literature. However, it was shown by B. Lagowski that N_2-10% Cl_2 released about a foot below the surface of an 0.8% Mg melt resulted in almost complete consumption of chlorine and that the magnesium removal efficiencies were 20% below 710°C and 90% above 710°C. This may be interpreted on the assumption that the primary product of the chlorination treatment is $AlCl_3$, although some $MgCl_2$ is also formed if sufficient Mg is present.

$$2Al_{\ell} + 3Cl_{2_g} \longrightarrow 2AlCl_{3_g} \qquad (1)$$

$$Mg_{\ell} + Cl_{2_g} \longrightarrow MgCl_{2_{\ell}} \qquad (2)$$

Liquid $MgCl_2$ present in the rising bubble may act as a solvent for both $AlCl_3$ (3) and Mg (4) thereby promoting the slower reaction

$$2AlCl_3 + 3\,Mg \xrightarrow{MgCl_{2_{\ell}}} 2Al_{\ell} + 3MgCl_{2_{\ell}} \qquad (3)$$

Below 710°C, reaction (3) will have to occur directly between gaseous $AlCl_3$ and Mg in the melt because $MgCl_2$ is solid, and this reaction is apparently much slower as evidenced by only a 20% efficiency below 710°C.

Thermodynamics indicates that the equilibrium Mg concentration for reaction (3) is about 10^{-5} wt%. Naturally, if $AlCl_3$ is permitted to leave the reaction area then a higher Mg concentration may be expected. In practice, the reaction is stopped when the Mg content reaches about 0.08%, because this meets the requirements. At the same time, the progressively longer times and greater production of $AlCl_3$ make it commercially unattractive to reduce Mg further.

Results

Experimental melts were made in gas fired 40- or 80-lb clay graphite crucibles. Chlorine or other mixtures were introduced into the bottom of the melts through graphite tubes, and any fluxes added were in the dried or anhydrous form. In later melts, a smaller clay graphite crucible was inverted to cover part of the top of the melt and thus form a "bell" where the products (solid, liquid, or gas) of the chlorine reaction would be trapped. The various experiments and their results are detailed below.

1) It had been suggested that under some circumstances magnesium might be lost by selective oxidation. A melt was maintained at 750°C and agitated by blowing dry nitrogen through it. Although an appreciable oxide and dross cover was formed on the melt, analysis showed that the magnesium content of the melt was unchanged, i.e., selective oxidation had not occurred.

2) A second small melt was then covered with $MgCl_2$ flux in which Mg is slightly soluble (4), and the experiment was repeated. This time, the flux prevented apparent melt oxidation, but the Mg content of the melt decreased from 0.96 to 0.79% after a 20-minute treatment. It is postulated that Mg dissolves in the $MgCl_2$ flux, and the excess Mg then oxidizes at the flux-air interface, the oxide or oxychloride being incorporated in the flux. This is supported by the fact that the $MgCl_2$ becomes less fluid as the experiment progresses.

3) The same apparatus was then used for chlorine treatment of melts. The results showed that, if chlorine was introduced into such melts at a slow rate and providing the treatment temperature was above the melting point of $MgCl_2$ (710°C, 1310°F), the only product of the reaction was liquid $MgCl_2$ which floated to the top of the melt and formed a cover.

If the flow rate was increased beyond a limiting value, gas bubbles

appeared on the surface which contained Cl_2, $AlCl_3$, and HCl. Accurate analysis of these products proved impossible, but it was obvious that the 100% efficiency in Mg removal had been lost.

It was further observed that as the residual magnesium content was reduced, the flow of chlorine being constant, progressively more fume appeared on the surface of the bath to indicate progressively less efficient use of the chlorine. Analysis of the flux covers formed during these experiments showed that they were predominantly $MgCl_2$ with metallic Al globules, MgO, Al_2O_3, and spinel ($MgAl_2O_4$). Aluminum chloride was not found in the flux until obvious fume was coming from the bubbles breaking the surface at the end of the refining period.

From the above experiments, it was postulated that within the rising gas bubble, both $MgCl_2$ and $AlCl_3$ are formed as in Equations (1) and (2), and that the presence of liquid $MgCl_2$ promotes the further reaction of $AlCl_3$ and Mg as in Equation (3) provided there is sufficient $MgCl_2$, on the one hand, and sufficient time on the other. Further experiments concentrated on this aspect as it had the prospect of "fumeless" refining.

4) Accordingly, a small crucible was inverted in the metal surface where it trapped added flux in the form of a ternary low melting point (660°C, 1220°F) eutectic (4 pts KCl, 2 pts $MgCl_2$, 1 pt LiCl) known to have a high solubility for $AlCl_3$ (3). The crucible was also arranged so that it would trap any reaction products rising from the chlorine flushing system.

In preliminary experimentation with this unit, though the hydrogen content of the melt was markedly reduced, there was no evidence of gas bubbles escaping from below the submerged rim of the "inverted bell" crucible. It is postulated that the hydrogen was being entrained by rising bubbles (of Cl_2 or $AlCl_3$) and swept into the bell from which it escaped by diffusion through the walls into the furnace atmosphere (hot crucibles are known to be readily

permeable to hydrogen from combustion processes).

5) Using the "inverted bell" system, it was found that chlorine could be bubbled through the melt for an appreciable time without any escape of gas or fume from below the rim of the bell, and it was apparent that, under these circumstances, the end product of the reaction must be $MgCl_2$ because at these temperatures $AlCl_3$ is a gas and would escape after the relatively small volume of the inverted crucible was filled.

Under a particular set of experimental conditions which appeared to be controlled primarily by depth of chlorine lance immersion and chlorine flow rate, fume would eventually begin to escape from below the rim when the magnesium content had been reduced to a certain level. This was termed the "end point" for convenience, although it must be appreciated that it did not represent the point at which magnesium could not be further reduced by chlorine treatment. With low flow rates, the magnesium could be reduced from 0.5% to as little as 0.02% before fume was evolved.

6) The above experiments were repeated at somewhat higher chlorine flow rates on a series of commercial and experimental alloys to which 0.5% Mg had been added. Figure 1 gives the results for the Al-Cu series and shows the Mg concentration at which fume first became apparent at the flow rate indicated. Figure 2 gives the same information for the Al-Si series.

From these figures, it will be seen that the slopes of the curves are all about the same showing that all alloys are equally sensitive to the Cl_2 flow rate. Within the Cu series, increasing Cu caused an increase in the "end point" for a given flow rate and addition of up to 2% Zn to the 4% Cu alloy reduces the end point. It will be seen that the results bracket the binary Al-Mg plots and the same effect was observed with the silicon series. It would appear therefore that the presence and amounts of additional

elements affect the rate at which Mg can be stripped out of the melt by Cl_2, but the results are insufficient to predict the extent of this for any given composition of the complexity likely to be encountered in a scrap metal charge. Although this is not shown on the graphs, there was some indication that, as the total alloy content was increased, it became increasingly difficult to reduce the Mg content below 0.1% without fume evolution, even at very low chlorine flow rates.

Summary

Under certain conditions it is possible to both degas and remove magnesium to acceptable levels (0.1%) with chlorine without evolving either fume or noxious gases.

This development relies on the further reaction of $AlCl_3$ formed during the chlorination process with magnesium via the medium for a liquid flux, which is essentially $MgCl_2$. The chlorine treatment must be performed in an enclosed space (so that no unreacted chlorine, $AlCl_3$ nor $MgCl_2$ can escape) at a rate compatible with the speed of the reaction. This varies with operating factors such as length of bubble path, agitation, and type of alloy, and is directly proportional to the Mg content of the bath.

The results explain why commercial magnesium removal performed under similar enclosed conditions is more effective than the normal industrial technique of chlorine lancing directly into the reverberatory furnace bath (5). They also explain the technology behind a "Fumeless Demagging Unit" recently announced by Alcoa which, it is stated, eliminates the need for pollution control equipment (6).

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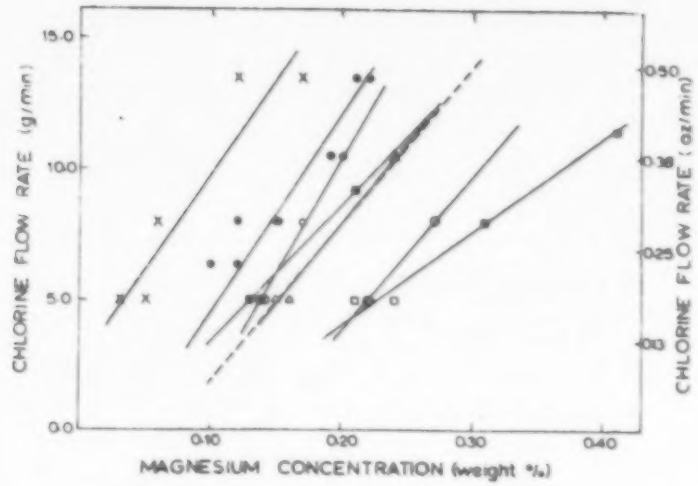
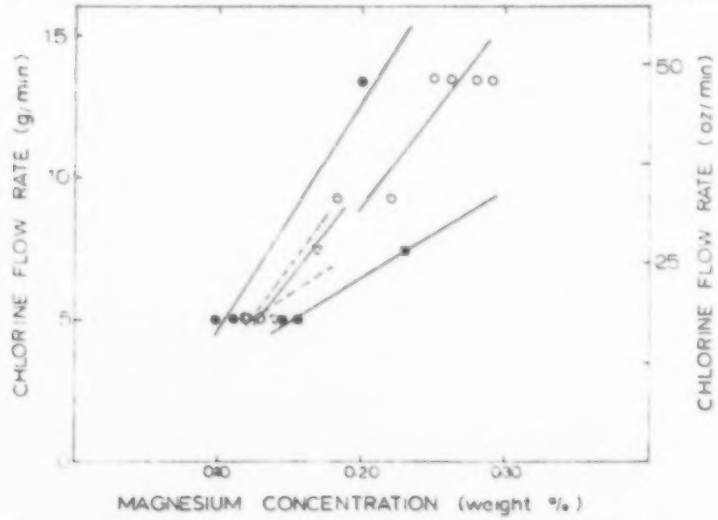


- - - - -	No Addition	□——□	4% Cu 0.7% Fe
×——×	1% Cu	○——○	4% Cu 0.7% Fe, 0.8% Zn
○——○	2% Cu	■——■	4% Cu 0.7% Fe, 2% Zn
△——△	3.5% Cu	●——●	4% Cu 0.4% Fe, % Si, 0.2% Fe

Figure 1. "End point" (Mg content at which fume first evolves) vs chlorine flow rate for different Cu-containing alloys.



○——○	No Addition	▽——▽	7% Si
-·-·-·-	2% Si	■——■	7% Si 1% Zn
●——●	3.6% Si	○- - -○	6½% Si 0.6% Fe 1% Zn

Figure 2. "End point" vs chlorine flow rate for Si-containing alloys.

REDUCTION OF TOXIC DUSTS FROM PYROMETALLURGICAL PROCESSES

by

G.E. Viens

ABSTRACT

Work has continued on all the projects outlined at last years seminar. The major effort has been concentrated on those projects in which industrial interest was highest. The shaft-electric smelting project was reactivated because of industrial interest. The process for the pyrometallurgical treatment of fly-ash residue from the Athabascan tar sands was advanced to the point of submitting a proposal to industry for a large-scale pilot plant operation.

PROGRESS IN 1972

Work was continued on all the projects outlined at last year's seminar, but the major effort was concentrated on two projects in which industrial interest was very high.

During the early part of the year considerable time was expended on the development of a pyrometallurgical process for the recovery of nickel and vanadium from the fly ash which is a residue from the extraction of petroleum products from the Athabascan tar sands. The stock piles of this very fine residue may very easily be shifted by wind. After the pyrometallurgical treatment, the non-metallic residue is in the form of massive slag which either forms excellent inert land fill or can be converted to rock wool insulation. The small-scale work on this project has been completed and a proposal for a continuous pilot-plant operation has been submitted to industry.

At the request of a Canadian steel company, the EMR shaft-electric furnace project was reactivated. This company's interest lies in obtaining a method for economically producing a moderate tonnage of pig iron by a process which produces relatively little pollution. One 12-day pilot-plant experiment has been completed and the data are currently being analyzed. It is expected that at least one more experiment will be performed in Ottawa in the near future. If their experiments are successful the company has stated that it intends to then move the program to a larger furnace in its own plant.

THE INSTABILITY OF ACIDIC TAILINGS AREAS AND THE RECOVERY AND RECYCLE OF PRODUCTS OTHERWISE LOST BY LIME NEUTRALIZATION

by

A.J. Gilmore

ABSTRACT

During 1972, the danger of toxic metal hydroxides being dissolved and polluting our water environment was realized. This situation arises from the instability of these hydroxides exposed to acidic conditions on dump areas. The metal content of lime sludges being discharged is, in some cases, greater than that of marginal ores being treated. Field and preliminary laboratory observations are substantiated in the literature.

An alternative approach to pollution abatement would be to recover these toxic metals and anions from mining and metallurgical effluents for recycle to existing industrial operations "inside the factory fence" (1). Indications are that effluents from such a recovery and recycle program would satisfy water quality criteria.

PROGRESS IN 1972

1. The Potential Instability of Base Metal Hydroxides in Tailings Areas

A laboratory study examined the solubility of precipitated base metal hydroxides, as formed by lime neutralization of acid effluents containing soluble metals. These hydroxides are normally discharged with lime sludges to tailings areas. The metallic contamination of water resources has been noted in a task force report (2). Contamination started from acidic conditions produced by rainfall and oxidation of pyrites in stripped coal beds.

Consequently, a slurry of a precipitate, produced by liming an acid quarry water in New Brunswick was conventionally leached at acid adjusted pH-levels of 7, 5, and 4. The dried precipitate contained the equivalent of 34 lb/ton for each of copper and zinc. The dollar value, at current prices, is about $23.50/ton precipitate.

The solubility of the base metal hydroxides, under acidic conditions, is shown in Table 1.

An increase in weight loss of precipitate and base metal concentration of filtrate, with an increase in acidity, is clearly shown.

Subsequently, the rainfall in the Ottawa area between June and October 1972 was sampled, and pH-measurements were found to be in the 4.5 to 4.7 range.

Table 1

The Solubility of Toxic Base Metals in a Lime Precipitate at Various Acidities

Determination	pH of Leach		
	7	5	4
Cu ppm	0.3	47	1520
Zn	5.3	566	2328
Wt. Loss %	1.2	1.6	4.0

These results significantly illustrate the hazard created, firstly, by the gradual erosion of toxic constituents and, secondly, by the accelerated erosion of toxic metals. Firstly, in urban industrial areas, lime sludges from the neutralization of some plating waste effluents are discharged to municipal garbage dumps. Gradual erosion could occur

during percolation of acidic rainwaters through municipal dumps and hence to our water environment.

Secondly, pyritic tails after mill processing are discharged with lime sludges to disposal areas. There, acidic rainfalls of about pH 4.5 (3) combine with sulphuric acid to dissolve base metal hydroxides in the sludge by a percolation leach of the disposal area. The sulphuric acid is produced by the atmospheric oxidation of pyritic minerals. Toxic metals and pH-measurements as low as 2 have been detected in seepage waters from idle tailings areas (4).

In addition, an examination of the solubility curves for hydroxides of copper and zinc shows these compounds to be soluble with an increase or a decrease in pH beyond the optimum value for maximum precipitation.

Further studies related to this problem are in progress.

Product Recovery

The recovery and recycling of valuable metals and by-products from industrial acidic effluents is an alternative approach to lime neutralization and the production of voluminous sludges containing soluble forms of base metals. Techniques for metal recovery were outlined at the 1972 seminar (5). Details of these processes have been drafted for editing. Two more techniques on product recovery from mine and mill effluents are briefly outlined.

(a) Recovery of a Zinc Oxide from Mine Water

A product of 68% Zn and a total of <0.2% of Cu, Ca, and Mg has been recovered on a laboratory scale from a mine water received from northeastern Quebec. This near-neutral mine water contained 380 ppm Zn and 730 ppm Ca plus Mg with negligible amounts of Cu and Fe. Adsorption of the metals on a sulphonic acid resin, a common household water softener, gave a neutral effluent of 20 ppb Cu and 10 to 50 ppb Zn, which is tolerable for water recycle or discharge to the environment.

Caustic neutralization of a fraction of the acidified lime regenerant, followed by a 200°C calcination of the precipitate, resulted in a product containing 68% Zn.

This preliminary study illustrates the chemical feasibility of recovering a high-grade zinc product in the presence of calcium and magnesium cations by a household water-softening treatment and a selective elution-precipitation technique.

Further work is currently in progress.

(b) A Sulphate Recovery Process

A sodium sulphate (Na_2SO_4), identified by X-ray diffraction analysis, has been prepared in the laboratory from an acid mine drainage (AMD) water. A sulphate concentration of 5800 ppm in the AMD water was reduced to <9 ppm by adsorption on the carbonate form of a quarternary ammonium exchanger.

The sulphate was concentrated 5½ times in a fraction of a carbonate elution of the exchanger. Acidification and evaporation of the fraction at ambient temperatures produced the Na_2SO_4.

Arrangements have been made to do further work, with this technique, on the overflow from an Elliot Lake tailings dam. This technique, if workable, would be ideal for the water-quality program of the area because;

(1) a mill recycle of clean water is under consideration,

(2) guidelines, imposed by provincial water authorities, will probably necessitate a decrease in the anion content of effluents discharged to the area water resource,

(3) an excess of the exchanger and related equipment is available from idle operations in the area,

(4) heat for the evaporation and crystallization of the sodium sulphate may be available from leaching pachucas,

(5) potential markets for the sodium sulphate by-product are in rayon and nearby pulp and paper industries.

2. Discussion and Conclusions

The hazard of continual degradation of metallic precipitates and minerals in our disposal areas as a pollutant source to our water environment has been noted. Lime neutralization as a process for the pollution abatement of acidic mine and metallurgical effluents may not be economically beneficial over the long term. The solubility of toxic metal hydroxides under acidic conditions of environmental leaching in dump areas creates the danger. In addition, the discharge of voluminous unstable sludges means the discard of valuable metals in greater concentrations than in some marginal ores being processed.

Methods have been outlined for a recovery and recycle program for the pollution abatement of some toxic effluents "inside the factory fence" (1). The recovery of valuable metals and by-products has been shown to be chemically feasible. The effluents from recovery programs could be recycled to industrial operations, but, eventually, would be discharged to the water environment.

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AN EXPERIMENTAL STUDY OF THE WEATHERING OF MILL TAILINGS

by

A. Jongejan

ABSTRACT

Experiments are being conducted separately on each of the chemical, physical, and microbiological aspects of the weathering of mill tailings. After information has been collected on each of these aspects, their interactions will be studied.

A third and final preliminary percolator run evaluated the possible influences of aeration, the introduction of lime, and the introduction of an ion-exchange resin on the pH, redox potential, and conductivity of the water percolating through tailings from the Heath Steele Mine in New Brunswick.

Methods of determining Ca, Cu, Zn, and Na in very small water samples were developed using flameless atomic absorption spectrophotometry.

The principal work during the review period, however, concerned the mineralogical analyses of tailings samples from various mining companies in Canada. This work was undertaken to obtain information about the similarity and diversity of the mineralogical compositions of tailings in general.

The study of the microbiological aspect is focussed on the identification of micro-organisms living in acid water draining from a tailings pond of a small gold mine in Quebec.

Water flow-rate experiments are being conducted, not only because of the interest in the effect of the exposed grain surface area on the chemical weathering processes, but because of the purely physical question concerning the proportion of percolation to surface run-off of rain. This is important to revegetation projects.

PROGRESS IN 1972

The principal purpose of the percolator experiments is the evaluation of the effect of synthetic mixtures of natural minerals on the composition of water percolating through these mixtures and, afterwards, to complicate the effect by the action of different micro-organisms. Although the mineral pyrite is the major source of the acidity of drainage water and carbonates can be assumed to counteract the acidity, information has to be obtained about variations in the quantity and in the grain size of pyrite and other sulphides, of carbonates, and of other minerals present in tailings produced in different locations. For this purpose and because the information could also be used in the project on the re-use of mineral wastes that is being conducted by the Mineral Processing Division, tailings samples from various mining companies were collected. The mineralogical analysis of eight samples has been finished, and that of another five is in progress. The results of microscopy estimations, X-ray diffraction, and thermogravimetric analysis of fractions obtained by wet screening and by use of the super centrifuge were combined with analytical chemical results to give estimates of the mineralogical composition of the samples.

The results already indicate large differences in composition. Although differences in grain size distribution are also indicated to a lesser extent, some grain-size differences may have a significant effect

on water pollution.

Preliminary percolator experiments designed to obtain an impression about the variables involved in the weathering process were concluded with an experiment concerning the effect of aeration, the introduction of lime, and the introduction of an ion-exchange resin in the flow-circuit. Although the lime initially produced a high pH in the percolating water, this effect was later reduced significantly and could be expected to disappear after more than 150 days. Aeration had little effect, except perhaps for an increased precipitation of carbonates. The introduction of an ion-exchange resin indicated the possibility of obtaining information about the total amount of iron that dissolves during a run. The iron normally precipitates to a great extent as ferric hydroxide. Although a percolator experiment on the dissolution of different grain sizes of pyrite could have been started, it was preferable for practical purposes to provide information on the effect of the mineralogically analysed tailings on percolating water. Therefore, a run is in progress in which seven of these samples are included. Samples taken during 1971 from actual tailings ponds of two of the companies concerned are also included. The pH, redox potential, and conductivity of the water are measured daily, while each of the elements Ca, Cu, Zn and Na is determined daily.

Approximately twenty different species of micro-organisms have been isolated from an acid and copper-bearing drainage water of a small gold mine in Quebec. Most of them appeared to grow heterotrophically in a culture medium that was acidified with sulphuric acid from pH 7 to 3. Tests used in standard identification procedures, adjusted to the nutrient requirements of the isolated species, have been started recently. It is very likely, however, that several of the species are little known and have not been described yet, so that the direction of this aspect of the

study will remain uncertain until all tests have been completed.

The physical aspects of the study are principally those related to the particle-size distributions and the surface areas of the tailings minerals. These two factors are included in those typifying the chemical properties of a particular tailings material and are thus considered in connection with the percolator experiments. In addition, attempts are made to obtain information on the physical aspects alone, particularly in connection with the water flow through a tailings pond in the field. Laboratory experiments are thus conducted dealing with the water flow-rate through columns of tailings contained in vertical glass tubes. The effects of differences in column length, of layering, of alternation with layers of sand, and of intermittant drying on the water flow rate are being studied; experiments dealing with the water flow rate in two dimensions will follow.

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ADSORPTION OF TRACE QUANTITIES OF METAL IONS BY CLAY MINERALS

by

H.F. Steger

ABSTRACT

The objective of this project is to evaluate the feasibility of using open-lattice silicates as adsorbers of trace quantities of metal-ion pollutants from mine waste waters. Although there are several types of open-lattice silicates, it was decided to begin the investigation using bentonite clays. On the basis of results obtained in acetate medium, two samples of bentonite clays out of a suite of eight specimens studied showed the greatest promise and further work was restricted to these two bentonite clays.

In 1972, the adsorption by these clays of trace amounts of metal ions in a synthetic thio-acid medium was studied. Early in this study, one of these clays, Aquagel, was clearly noted to be superior to the other for the intended purpose, and all further work was restricted to Aquagel.

PROGRESS IN 1972

The adsorption by Aquagel of trace amounts of iron, copper, zinc and lead, in the presence of 100-fold (or greater) excesses of sodium and calcium, from a synthetic thio-acid medium was studied. The amounts of metal ion adsorbed were found to depend on the nature and concentration of the metal ion, the number and total concentration of all such metal ions present, the pH of the medium, the amount of clay used, and the contact time of the clay with the medium.

The experimental evidence obtained to date indicates the adsorption

of trace metal ions does not occur by ion-exchange with the alkali metal or alkaline earth metal ions adsorbed on the clay. Likely, the trace metal ions are adsorbed at areas of structural breakdown. The result is a low capacity for trace metal ions. Though all metal ions are adsorbed to some extent, it is important that the total concentration of all metal ions be low for the clay to be effective in the reduction of this concentration. Furthermore, in a mixture of metal ions, the various metal ions will be adsorbed to different extents. Thus, it may not be possible to use Aquagel to adsorb one component in a mixture if the other components are more strongly adsorbed by the clay. Also, the relative concentrations of the components will determine the relative extent of adsorption of each.

The adsorption of trace metal ions by Aquagel occurs best at near neutral pH. The deviation from pH=7 at which adsorption continues to occur satisfactorily depends on the nature of the metal ion.

The effect of the amount of clay used per given volume of medium is linear. The more clay is used, the greater the adsorption capacity and, of course, the more metal ion is adsorbed.

The adsorption of trace metal ion by Aquagel does not occur instantaneously. It is important, therefore, that the contact time between the clay and the medium, be sufficient to let the clay and metal ion equilibrate.

Oftentimes, undesirably large concentrations of trace metal ions remain in mine waste water that has been neutralized by lime treatment. Because such waters usually have a favourable pH, bentonite clay may be useful in the final purification of this waste water. Indeed, treatment of a real sample of mine waste water from New Brunswick with Aquagel resulted in an appreciable reduction in the concentration of iron, copper, and zinc.

Because of the nature of the adsorption of trace metal ions by bentonite clay, it is quite possible that other abundant, inexpensive natural materials which are found near mining areas could be used instead of bentonite clay. A study of the potential use of such materials in this context is under consideration.

RECYCLING PROCESS WATER TO IMPROVE MILLING EFFLUENTS

by

D.E. Pickett

ABSTRACT

Regard for the environment and provincial regulations designed to protect the environment have required mining companies to take action to reduce to a minimum the amount of waste water released to surface streams and lakes from mines and mills.

Re-use or recycling of water reclaimed from tailings and concentrates is the most effective means of meeting the requirements. The objective of the research project on recycling is to assist the industry to recycle process water as soon as possible. Two simultaneous approaches were necessary:

(1) an intensive study of the literature to identify all sources of information on relevant technology, i.e. what resources were available; and

(2) a survey of the industry to isolate those problems of most pressing importance so solutions could be developed by concentration of research resources to meet minimum standards.

PROGRESS IN 1972

Following presentation of an initial progress report in 1971 a continuing record of the literature has been maintained by Mr. P. Bailey.

The industrial study is being made with the co-operation of the Canadian Mineral Processors (CMP). A questionnaire has been circulated to

all operating metallic ore mines by Mr. E. Joe, Secretary of CMP. To date, December 6, the response to the questionnaire is about 50% complete and it represents more than 80% of the base metal tonnage being mined but less than 10% of the iron ore tonnage.

Final analysis of the returns must await a more complete response but analysis of the replies that have been received indicates that:

(1) copper mines have few or no metallurgical problems with recycling of reclaimed process water; ten mills, treating 130 thousand tons per day, recycle all water possible from the tailing ponds and thickeners; the copper mills reporting difficulties are small operations with special problems;

(2) gold mines recycle most (50 - 80%) of process water in barren solutions but discard barren solution to avoid concentration of cyanicides; methods for economically treating this discard solution must be found very soon;

(3) experience at mixed base-metal (Cu-Pb-Zn or Cu-Zn) mills indicates a great deal of difficulty with recycling, so it is in this area that research must be concentrated;

(4) persistent, unavoidable problems are reported by mines that discharge large volumes of mine water; though most mills can use a portion of this water, excess mine water must be treated in a separate system before release; this indicates two fields of mining research -

   (a) minimizing the flow of water into mine workings, and

   (b) development of mine water treatment methods.

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A report will be presented to the Canadian Mineral Processors (CMP) after the survey is completed. A progress report will be presented to the CMP meeting in January 1973.

USE OF SOLVENT-IN-PULP AND CONTINUOUS ION EXCHANGE FOR ENVIRONMENTAL IMPROVEMENT

by

B.H. Lucas

ABSTRACT

Continuous ion exchange and solvent extraction of uranium from leach slurries were compared with respect to processing and economics. Although the two processes have comparable costs (45% lower than for the treatment of clarified liquors), the SIP (Solvent-In-Pulp) process uses much less water. Ion exchange, however, can extract trace amounts of metal values to acceptable levels and, because of its lower costs, continuous ion exchange may be suitable for treating dirty waste streams.

PROGRESS IN 1972

One objective of our solvent extraction program is to apply solvent-in-pulp (SIP) methods, using a sieve-plate pulse column, to the treatment of uranium-bearing leach pulps. If a successful SIP process was developed, it would mean that the current liquid-solid separation and washing steps could be eliminated, thus reducing the volume of process solution that would require neutralization before disposal. The effects of some of the parameters on solvent losses have been investigated. An investigation into the use of additives to prevent solvent losses by adsorption on the pulp solids has been started. Non-toxic biodegradable fish glue has given encouraging results. The proposed SIP flowsheet incorporates maximum water recycle with a small bleed.

One of our projects this year in the application of the resin ion-exchange process for the recovery of soluble metals has been the

construction of a multi-stage, fluidized-bed, IX adsorption column in circuit with a moving, packed-bed, regeneration column and a fluidized-bed washing column. This equipment was used to demonstrate that ion exchange can be used to recover soluble metal from waste mine or mill solutions that contain some solid material. Hydrodynamic studies on resins and ore leach pulps have been done. Clarified uranium ore leach solutions and leach pulps of 5 and 10 % have been used (1).

Another study was completed using the continuous ion-exchange multi-stage column to treat Falconbridge mine water containing 57 ppm Ni, 7 ppm Cu, and 2 ppm Fe. These metal values were reduced to 0.05, 0.01, and 0.04 ppm respectively. A synthetic mine water containing 41 ppm copper was also treated successfully. A paper is being prepared that includes costs. After bulk extraction from mine waters by ion-exchange, solvent extraction is being considered to separate the metals.

The continuous ion exchange column has been further simplified by going to a single stage. The use of inexpensive materials to construct a simple box is visualized. Initial results are very encouraging.

A comparison of the processing and economics of uranium recovery from leach slurries by continuous ion exchange and solvent-in-pulp has been made (2). These two routes have essentially equal costs which are about 45 % lower than the cost of treating clarified solutions. The ability of resin-in-pulp in a continuous ion exchange column to achieve low levels of metal values makes this a possible route for the treatment of dirty waste containing traces of metal values.

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RE-USE OF MINERALS WASTES

by

R.K. Collings

ABSTRACT

The prime objective of the mineral waste research program of the Non-Metallic and Waste Minerals Section is the recovery and conversion of these wastes into useful products. The materials of particular interest in this work are the solid mineral wastes from mining and mineral processing, metallurgical, chemical, and pulp and paper plants.

During 1972, five internal reports on sources of mineral wastes in Canada were completed. Work on one project, the use of waste phosphogypsum for gypsum products manufacture, was completed and reported on, while work on uranium tailings for glass manufacture and on calcium silicate residues from magnesium smelting was continued. Several new projects, including the manufacture of rock wool from asbestos tailings, the separation of clay fines from fibre in paper sludge, and an evaluation of waste fines from an Ontario-based nepheline syenite operation were initiated. In addition, mine tailing samples from 20 selected mines were received and processed as part of an overall Mines Branch Program. Laboratory study of these tailings showed that most contained substantial amounts of metallic sulphides and were therefore of little interest with respect to re-use. Several, however, including gold tailings from two Kirkland Lake mines, had relatively high silica contents and are being further investigated re possible application in the field of construction materials and ceramics.

PROGRESS IN 1972

1. Mineral Waste Inventory

Five internal reports of sources of solid mineral wastes in Canada - in the Atlantic Provinces, in Quebec, in Ontario, in the Prairie Provinces, and in British Columbia, the Yukon, and the Northwest Territories - have been completed. Mineral wastes are grouped under four categories in each report as follows:

1) mining and mineral processing plants
2) metallurgical plants
3) chemical plants
4) pulp and paper plants.

2. Examination and Evaluation of End-Use Potential of Selected Mine Tailings

In co-operation with three other divisions of the Mines Branch (Extraction Metallurgy, Mineral Sciences, and Mining Research), tailings from 20 selected mines were requested for study. These tailing samples were processed in the Mineral Processing Division (MPD) to provide representative samples for study by the co-operating divisions. As part of this program, MPD is providing information re size distribution, bulk density, specific gravity, etc. In addition, samples that appear, on the basis of physical and chemical characteristics, location, etc., to have potential re-use value are being further investigated in the Non-Metallic and Waste Mineral Section. High-sulphide tailings are of limited interest. However, tailings with a high non-metallic mineral content are of interest as potential source materials for construction materials, ceramic products, mineral fillers, etc.

3. Mineral Wool from Mine Tailings (A.A. Winer)

Tests are underway to determine the feasibility of producing

mineral wool from selected tailings from several metallic and non-metallic mines. In most instances, the waste requires the addition of acid and base components, e.g. silica and calcium compounds, to arrive at the desired mixture. Equipment is now being assembled to produce mineral wool on a laboratory scale.

4. Uranium Tailings for Glass (R.K. Collings)

Larger and more representative samples of high-quartz tailings from the Elliot Lake uranium mines were obtained and treated by high-intensity wet and dry magnetic separation, by electrostatics, and by froth flotation. Samples of the beneficiated products have been forwarded for chemical analysis. Though at least one glass company has expressed interest in this project, possible harmful effects, due to radioactive products in these tailings, may prohibit their use for this purpose.

5. Nepheline Syenite Tailings (G.D. Feasby)

One Ontario producer of nepheline syenite rejects 100 tons per day of waste fines. An investigation is underway to determine whether part of these fines can be recovered for use in glass manufacture or in certain filler applications.

6. Magnesium Metal Residues (G.D. Feasby)

Calcium silicate and calcium aluminate slags from magnesium and calcium production are being studied for conversion to a cementing material, to an insulating material, and for use as a soil conditioning agent. Waste dolomite fines from the same operation are being examined re use as a filler in caulking compounds, paint, etc.

7. Phospho-Gypsum for Gypsum Products (R.K. Collings)

Work on this project was completed during the year. A paper

summarizing the results of this work was prepared and presented at the Annual Meeting of the Canadian Institute of Mining in April, in Ottawa. This paper was published in the September issue of the CIM Bulletin. Several industrial groups have expressed interest in this project and in the utilizing of this material for gypsum products manufacture.

8. Waste Sludge from Pulp and Paper Plants (A.A. Winer)

An investigation is in progress to determine whether clay minerals in waste sludge from pulp and paper plants can be separated from wood fibre. Both fractions could be re-used if they could be separated economically. Various mineral separating techniques are being investigated.

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REVEGETATION OF MINE WASTES

by

G. Zahary and D.R. Murray

ABSTRACT

Revegetation of mine wastes is part of the Ground Control Program, Surface Workings Project carried out by the Mining Research Centre. One of the objectives of this project is to develop reclamation procedures for waste embankments. The revegetation study is a contribution to this objective.

Revegetation work is carried out under the direction af a full-time agronomist with the assistance of Ground Control personnel and is centered at the Elliot Lake Laboratory. The study is now in its second year. The first year's work consisted of a general state-of-the-art review of mine-waste revegetation technology as well as an assessment of the tailings areas, environmental conditions, and previous revegetation work in the Elliot Lake area. Some of this work was done in co-operation with the Soil Research Institute, Ottawa (1,2).

PROGRESS IN 1972

During the past year the principal areas of progress have been:

1) laboratory-based study of the physical and chemical properties of Elliot Lake uranium tailings;
2) establishment of experimental field plots or two tailings areas at Elliot Lake;
3) establishment of a laboratory consisting of a Growth Chamber and ancillary apparatus in which a preliminary study of the effect of fresh and oxidized tailings on plant growth was completed;

4) core sampling along a profile of the tailings embankment and pond; and

5) organization of a closed seminar on revegetation of acidic mine wastes and presentation of talks on revegetation to industrial audiences, e.g., Mining Association of Canada.

Contacts have been established with a number of mining companies engaged in revegetation work, agronomists in government and universities, and researchers concerned with vegetative cover on rough lands (3). In the future, present competence with highly acidic mine wastes will be maintained, but a greater effort will be made to define problems peculiar to revegetation of waste embankments and slopes.

1) Physical and Chemical Properties of Uranium Tailings

Laboratory work was done by using the facilities and under the guidance of the Soil Research Institute, Ottawa (4). The major conclusion from this work is that, although uranium tailings could be considered a soil on the basis of particle size, it is not a true soil because of the following deficiencies:

- high "air entry values" and water retention in fine tailings,
- low nutrient levels and no significant "cation exchange capacity",
- highly acidic and, to some extent, chemically reactive.

These deficiencees can be corrected more easily on coarse than on fine tailings.

2) Field Plots

Field plots must be maintained for a number of years before final conclusions are drawn. The work of others has indicated the following growth rating for grasses on tailings: Reed Canary, Creeping Red Fescue, Red Top, Kentucky Blue, and Brome.

These species were used to test rates of fertilizer application and depth of cultivation. Preliminary indications are that fertilizer applied at the rate of 100 lb/acre/month for the season is superior to 50 lb/acre/fortnight, 200 lb/acre bimonthly or 600 lb/acre in a single application at seeding. Cultivation to a depth of 0, 3, and 6 inches was tested and best results were obtained with 6-inch cultivation.

3) Growth Chamber Tests

Fifteen species of grasses were tested. On fresh tailings without neutralization, 11 of 15 grasses germinated of which Creeping Red Fescue and Tall Fescue were strongest. On the oxidized tailings treated with limestone, 7 of 15 plants germinated and all were weaker than those on fresh tailings. Tall Fescue and Buckwheat were strongest in this case.

4) Tailings Sampling

Core samples, 2-inch diameter to a depth of 20 feet, were obtained at three locations on a profile between the embankment and pond area of a tailings area. At each location an undisturbed core was obtained as well as a core of disturbed material. The holes have been cased and are being used to measure variations in the water table over a season as affected by layering of fine and coarse tailings.

Tests on the disturbed samples indicate oxidation of pyrite is restricted to the top 2 feet of the wastes and that the tailings are nearly neutral at depths below 3 feet. Percolation rates on the undisturbed samples are under way and the results of this study will be reported shortly.

5) Seminar on Revegetation of Acid Mine Wastes

A closed seminar was held at the Elliot Lake Laboratory to discuss local revegetation problems. All the major mining companies were represented

as well as the Soil Research Institute and Ontario Agricultural College, Guelph. Field sites were inspected and a good deal of information was exchanged by the participants. The proceedings were informal and minutes have not been published.

Such interesting points were raised as:

- the need for a long-range study of the breakdown of tailings into a soil which will support growth on a self-sustaining basis;
- the possibility of developing plant types which would tolerate the toxic tailings environment;
- the need for a whole new technology for cover crops as distinct from agricultural crops.

Most participants thought the format was a good one and indicated their interest in attending another such seminar.

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COAL MINE REFUSE BANKS

by

T.E. Tibbetts

ABSTRACT

The Fuels Research Centre for the past several years has been involved in studies concerned with the clean-up of waste dumps resulting from about 100 years of coal mining in Nova Scotia. This involvement originated with a general public awareness of and opposition to environmental pollution and demands from the residents of the town of Springhill where a waste bank is burning.

PROGRESS IN 1972

Although the burning waste bank at Springhill still casts its obnoxious* fumes over the town, no action was taken following the Mines Branch report with an engineering proposal for reclamation of coal and rehabilitation of the land.

However, a direct outgrowth from the suggestions for reclamation of the Springhill waste bank was the testing in 1972 of three waste banks at Stellarton, Nova Scotia. About fifty holes were drilled by the Nova Scotia Department of Mines and the cores were evaluated by the Fuels Research Centre.

It is estimated that the three banks contain 1.1 million tons

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*This description is chosen rather than "hazardous" to avoid conflict with Environment Canada which has concluded that no health hazard exists. It is not known to the writer if mental health is considered in the conclusion.

of material that contains 57 per cent ash and that about 26 per cent of the material is recoverable as coal that contains 20 per cent ash.

The technical and economic evaluation apparently has been bolstered by favourable political winds as witnessed by a recent announcement by the Nova Scotia government that the federal and provincial governments will together put up $1.1 million for a coal reclamation project at Stellarton to provide work for 47 McBean coal miners.

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UTILIZATION OF MINERAL WASTES IN CONCRETE

by

N.G. Zoldners

ABSTRACT

The Construction Materials Section is engaged in projects dealing with the utilization of various industrial mineral wastes such as slags from steel-making plants and precipitator dusts from different industrial installations.

A study is underway on the use of expanded blast-furnace slag as a light weight aggregate in concrete. Strength properties as well as the heat resistance of such concrete have been investigated.

Pozzolanic properties of finely divided industrial wastes were determined to evaluate the use of these wastes in concrete. Materials such as wash-residue from slag cooling ponds, fly ash from thermal power plants, calcined shale dust, siliceous precipitator dust, and silica flour were investigated.

Expanded slag concretes, with and without partial replacement of portland cement by pozzolanic materials, were exposed to various elevated, sustained, and cyclic temperatures to study the effect of these micro-fillers on the heat resistance of concrete.

INTRODUCTION

Blast furnace slag is a by-product of the manufacture of pig iron. It amounts to about 0.3 to 0.4 ton of slag per ton of iron in modern furnace operations. The slag is tapped at about 1500°C and, depending on cooling procedures, various types are obtained. When the slag is allowed to

cool slowly, it solidifies into a grey, crystalline, stony material, known as air-cooled, dense slag. By rapid chilling, using a limited amount of water, a porous, lightweight material called "expanded slag" is produced. By quenching the molten slag with high-pressure water jets or by use of special mechanical devices, glassy lightweight 1 to 5-mm pellets are produced.

The first phase of the project covered structural properties of concrete made with granulated slag aggregate; in the second phase, its durability under freezing and thawing conditions was studied; and, in the third phase, its heat resistance under sustained and cyclic temperatures using microfillers as thermal stabilizers was investigated.

PROGRESS IN 1972

Phase 1 Two series, each consisting of five slag-concrete mixes covering a wide range of cement content and identified as A and B, were prepared. The compressive strength and density of 6 by 12-in. test cylinders were determined for both wet-cured and air-dried 7- and 28-day test specimens.

Series A mixes were all-lightweight slag in which both the coarse and fine aggregates were expanded slag. Series B mixes were semi-lightweight with expanded slag as coarse aggregate and natural sand as fine aggregate. The results indicate that superior lightweight concrete, having a 28-day compressive strength up to 6000 psi with an air-dry density of from 115 to 117 lb/cu ft, can be produced using pelletized expanded slag material for both coarse and fine aggregate.

Phase 2 Two series, each consisting of two slag-concrete mixes with low and medium cement content and identified as C and D, were prepared and the relative frost resistance or durability of the concrete under Canadian conditions was determined. Series C consisted of two all-lightweight slag

mixes with cement contents of 530 and 700 lb/cu yd. Series D consisted of two semi-lightweight slag mixes with cement contents of 350 and 560 lb/cu yd. All mixes were air-entrained with air content ranging from 8 to 10 per cent. After 1000 cycles of freeze-thaw exposure, no significant damage to the test beams was observed. The loss in flexural strength as compared with that before exposure was 10 and 15 per cent for Series C, and 4 and 3 per cent for Series D, indicating good frost resistence.

Phase 3 This phase of the project is concerned with the use of mineral waste materials in concrete for exposure to elevated, sustained, or cyclic temperatures.

In order to increase the heat resistance of concrete made with normal portland cement, two methods were employed:

(1) The use of heat-resistance aggregates - In this study, expanded blast-furnace slag as minus 3/8-in. granulated pellets was used for both coarse and fine aggregates.

(2) The use of microfillers as thermal stabilizers of portland cement - Two pozzolanic materials, fly ash from Lakeview thermal power generating station of Ontario Hydro at Mississauga, Ontario (CM 491) and silica flour from an autoclaved concrete block plant at Hamilton, Ontario, (CM 500), were used in this phase a microfillers in concrete mixes prepared for thermal-exposure studies.

In Series E, straight portland cement and, in Series F, a blended portland-slag cement were used as binders.

Results of this work are not yet available.

CONCLUDING REMARKS

The limited data obtained in this project so far warrant these imcomplete findings:

1) The results from completed Phase 1 of the project indicate that superior lightweight concrete, having a 28-day compressive strength up to 6000 psi with an air-dry density from 115 to 117 lb/cu ft, can be produced using pelletized expanded slag material for both coarse and fine aggregate.

2) Air-entrained concrete made with expanded-slag pelletized aggregate in Phase 2 of the project showed excellent frost resistance, even after 1000 cycles of freeze-thaw exposure.

3) Though Phase 3 is not completed as yet, some observations may be of interest:

   (a) The blended portland slag cement (Series F) showed satisfactory strength development in concrete; however, there seems to be no advantage in using it in concrete exposed to elevated temperatures.

   (b) The results indicate that, in comparison with straight portland cement concrete, the use of 25 per cent replacement of cement by fly ash (Series G) resulted in about equal strength under standard curing conditions, but showed about 10 per cent higher residual strength after exposure to temperatures up to 500°C.

   Partial replacement of cement by silica flour (Series H) reduced the normal strength of concrete by a value related to the amount of cement being replaced; the percentage of residual strength increase after firing was about the same as was observed with fly ash replacement.

   (c) The results obtained by replacing portions of the cement by the two types of microfillers used in this study are

not conclusive, but must be established more precisely by further experimental work.

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CONTRIBUTION TO ENVIRONMENTAL IMPROVEMENT BY MINERAL PROCESSING TECHNIQUES

by

R.A. Wyman

ABSTRACT

The Industrial Minerals Milling Section's involvement in activity related to environmental improvement extends over the past decade. Originally the prospects for recovering valuable non-metallic minerals from plant discards was the chief concern. Though this continues, it has evolved into a co-operative effort by the sub-division. In addition to investigations on recovery from tailings, such assistance as crushing, screening, riffling, blending, and drying are provided as required by other sections. At the same time, the demand for consultative services has increased in proportion to the increase in pollution abatement activity, as well as the demand for employment of mineral processing techniques to abatement problems which are not of mineral industry origin.

Selective machine sorting underground and using the discard material for void filling would substantially reduce the amount of surface waste disposal necessary. The separation of halite from sylvite for this purpose was chosen as an appropriate subject for initial trials.

Flotation frequently plays a part in the development of processes for the concentration of industrial minerals. A policy of seeking degradable reagents which would effect the required separation has been followed for several years. The purpose is to ensure that liquid plant effluents rapidly become innocuous and that solid plant products can be rewetted as required.

PROGRESS DURING 1972

Recovery of Valuable Constituents from Mineral Waste

In addition to co-operation on the requirements of other sections in this area, flotation tests indicated that Rio Algom tailings could be beneficiated. The recovered sand was submitted to the Non-Metallic and Waste Minerals Section and preliminary tests on glass melts indicated the sand quality was good. Nepheline syenite waste was upgraded by removing magnetics from the very fine material.

Separation of Halite from Sylvite

Studies of material from three areas in Saskatchewan indicate substantial differences in potassium-sodium association. Prospects for separation by photometric means were shown to be fair for material from one area, moderate from the second, and poor from the third.

Degradable Flotation Reagents

The section continued to be associated with the operation of the Kaiser Celestite Mining Company's beneficiation plant in Nova Scotia which employs a degradable system developed by the section. Work continued on two degradable flotation systems for the Tanco project at Bernic Lake, Manitoba. The first was for flotation of amblygonite and the second for spodumene. Further pilot plant work showed that the Mines Branch process for recovery of barite using biodegradable sodium oloeyl taurate was viable.

Miscellaneous

A method was developed for removing silt from bark used as boiler fuel to reduce the discharge of fly ash to atmosphere.

A method is being sought for separating kaolin from wood fiber to allow recycling of both products rather than to discard them.

Advice was provided on the pulverizing of glass to be mixed with

silt as a radioactive tag for use in studying the distribution of solids by conveying currents in the Great Lakes.

Advice on the application of photometric sorting to glass particles was provided in connection with garbage recycling.

Recent Related Reports

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IDENTIFICATION OF SOURCES OF OIL SPILLS

by

H. Sawatzky

ABSTRACT

This project is being done with work on low-grade crude oils that have high sulphur contents. The methods that have been or are being developed for separating various components of the oils are being applied to the identification of sources of oil spillages.

In this work the identifications are made by gas chromatographic analyses. Oil distillate fractions with narrow boiling ranges are subjected to gas chromatographic separations according to types of oil components. These oil fractions have high boiling points, so non-conventional thermally stable inorganic chromatographic columns have been developed for the separations.

During 1972, this work was done by two professionals and one non-professional. Financial support was obtained from the Inland Water Branch of the Department of the Environment. The progress of the work in 1972 that has some bearing on the method of identifying oil spills is detailed in four reports.

PROGRESS IN 1972

The initial distillation step in our method of analysis has been replaced by a gas chromatographic simulated distillation. Because only small quantities of distillates are required, this is much quicker than conventional distillation and leads to better results during further gas chromatographic separations according to the types of constituents in oil.

A number of new thermally stable inorganic chromatographic columns have been developed that are superior to those formerly used. Also, a detailed study has been made as to how separations occur in these columns. The data are treated in terms of specific and non-specific interactions which is a great aid in interpreting the results. A paper on this work has been submitted and accepted for publication in the Petroleum Preprints of the American Chemical Society and will be presented at the next ACS meeting.

A presentation of our methods was made a a seminar on methods of identifying oil spills that was sponsored by the RCMP crime laboratories. It appears obvious that, for very similar oils, our methods offer many advantages over those used to date.

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